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AND ABSTRACT OF THE LITERATURE

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The Industrial Physician and the Qualifications Essential to his Success

An Interchange of Physical Examinations in Industry

Physiological Effects of Automobile Exhaust Gas and Standards of Ventilation for Brief Exposures
(Continued)

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DOES THE MAGNETIC FIELD CONSTITUTE AN INDUSTRIAL HAZARD?*

C. K. DRINKER, M.D., AND R. M. THOMSON

From the Laboratory of Applied Physiology of the Harvard Medical School

MEN achieve undeniable enjoyment and comfort from attributing misfortune and disease to influences which they do not understand. Thus, there is a large group who are quite satisfied with astrological explanations for an epidemic of influenza, and in times past there have been even larger groups whose ideas of disease rested upon a jumble of electromagnetism and fictitious forces of human magnetism, all so vaguely considered as to be entirely mystifying and, therefore, entirely satisfying. One might write at length of individuals who thus are happy in explanations which are not hampered by efforts to seek the truth.

In view of the frequency with which mystifying phenomena have been described as causal agents, it is not surprising that even within fairly recent years many extraordinary physiological effects have been claimed for the magnetic field; even in serious discussions the possibility that the field may effect cures of nervous disease has not been overlooked. Our attention was drawn to the subject in the course of investigations upon chronic poisoning by manganese (1). The affected workmen had, with few exceptions, been exposed to strong magnetic fields and the question — already suggested by Casamajor (2) — arose as to whether these exposures might not have something to do with causing the symptoms observed. The poisoning in question occurred in men working in an atmosphere heavily laden with ore dust, much of which was strongly attracted by the magnet, and the questions arising were of two sorts:

1. Is it possible that particles of manganese-bearing mineral deposited in the body are caused to penetrate more rapidly if the individual carrying them passes in and out of strong magnetic fields?

2. Does the magnetic field alone in very great strengths produce any measurable physiological effects?

The first of these questions we have never attempted to answer since a progressive reduction of dust, in the neighborhood of the large magnetic separators used in the mill involved, rendered it of no direct importance. The second question offered an opportunity to test the effect of stronger magnetic fields than have ever been used in biological work, and we were, accordingly, interested in undertaking to find an answer to it. The results, though entirely negative,

* Received for publication March 30, 1921.

are given in some detail in order to establish thoroughly the harmlessness of work in the neighborhood of extremely powerful electromagnets.*

Hermann (3), in a paper published in 1888, discusses previous scientific work with the magnetic field, together with the vast amount of charlatanry which has grown up around "magnetism" as a result of the use of magnets by hypnotists and others, and gives also an account of physiological experiments carried out by himself. Readers interested in the earlier literature on the effect of the magnetic field are referred to this paper. Under appropriate conditions Hermann found that certain fundamental properties of muscle and nerve were unaffected by exposure to magnetic fields. Unfortunately, however, he gives no information as to the actual field strengths operative in his experiments. This same criticism applies to other biological work with the magnetic field, the observations of Peterson and Kennelly (4) being excepted.

In 1892, Peterson and Kennelly made experiments with magnets in the Edison Laboratory at Orange, New Jersey, in order to test out extravagant claims then current as to the therapeutic effect of the magnetic field. A quotation from the paper of these investigators will illustrate the degree to which magnetism commanded attention at that time (4).

> The status of magneto-therapy in America may be inferred from some quotations from the third edition of Roberts Bartholow's *Medical Electricity*, 1887. Under the caption of Physiological Effects of Magnet Applications he says: "We know that a current circulates in a magnet. If a powerful horseshoe magnet is brought near to the skin, opposite electricities are attracted to the poles and currents are induced. About the point of application, therefore, the skin will be acted on directly by the magnetic current and by an induced current. The production of physiological effects, which can be recognized, is therefore merely a question of the magnetic strength."
>
> He then quotes Dr. Vansant as assuming the body to be diamagnetic: "By applying north and south polarity to different parts, very extensive subjective impressions are experienced; they are of two classes — of heightened organic activity, and the opposite condition."
>
> He then adds: "That impressions of a very decided kind are produced by the application of strong magnets is evident in the experience of Dr. Proust and Dr. Ballet, who continued a course of investigation begun by Charcot at Salpêtrière." They ascertained that magnets could not be applied with impunity, for, if applications were prolonged, pains were felt in the epigastrium and thorax, making respiration painful, digestion was disordered, and boulimia brought on. These results were so uniform that there seemed to be no doubt of their genuineness in the minds of the investigators.

In their first experiments, Peterson and Kennelly employed a magnet with a field intensity of 5,000 c.g.s. lines per square centimeter. They tested this field upon dried hemoglobin, fresh blood, ciliated epithelium, and the capillary circulation, without observing the slightest effect. They then placed a dog for five hours in a field with a strength of 1,000 to 2,000 c.g.s. lines per square centimeter without observing any change in the animal; and, finally, they tested the effect of field strengths of 2,500 c.g.s. lines per square centimeter upon themselves. In these latter efforts a variety of types of exposure were used but all resulted negatively, justifying their conclusion that the human body is apparently quite uninfluenced by magnetic fields of moderate strength.

Pfeffer (5), in 1903, discussing the possible actions of the magnetic field upon growth, can find no convincing evidence that any effect has been obtained. Ewart (5), in an editorial note, suggests that this is possibly due to weakness of the fields employed and that theoretically one should be able to affect living protoplasm provided strong enough fields are used.

* These experiments were made possible by the New Jersey Zinc Company through the loan of one of their large electromagnets of the type employed in the process at Franklin Furnace, New Jersey.

In all the experiments mentioned so far, with the exception of several by Peterson and Kennelly, a continuous current was used and the field strength was steady and unvarying. This condition is also true of the industrial situation which we have cited. In the case of solenoids traversed by alternating currents an interesting type of actual physiological effect was noted first by d'Arsonval (6) in 1893, and has been commented upon by several later experimenters (7) (8) (9) (10). Many of these observations, as for example those of Sylvanus P. Thompson (11), are considered by their authors to be the first note of the phenomenon ever made. That a definite and easily obtainable physiological effect does, therefore, arise in the neighborhood of a sufficiently powerful alternating field cannot be doubted. If the head is inserted in a coil or if it is brought close to a coil through which a strong alternating current is passing, a flicker of light is noticed, and this is perceived with the eyes open or closed, and in a dark or a light room. There is apparently no doubt that a definite visual sensation is induced and that it can be made to vary with current strength and the relation of the head to the magnet. Dunlap (12, p. 70) describes the sensation as follows:

> With 480 amperes of 25-cycle current (20 volts) a much more striking result was obtained. With my head below the level of the coil, and with my eyes open, the flicker was strongly noticeable, although the room was brightly lighted by afternoon daylight. The whole visual field quivered as if illuminated by a rapidly intermittent light. Several other subjects made a similar observation, although in some cases the flicker was noticed only in the less illuminated parts of the visual field, as where shadows fell in the room. With the head inside the coil the flicker was so pronounced as to be intensely disagreeable.

There is no explanation of this eye effect but at the same time there is no evidence that it causes damage. We may sum up, therefore, by saying that the scientific literature upon the physiological effects of the magnetic field is negative in so far as the use of constant fields is concerned, and in the case of alternating fields does not contain evidence of an effect which is harmful even when the experimenters employ much more severe exposures than would ever be experienced in any industrial operation.

Experimental Observations

a. Magnetic Fields. — The magnet used was a very large one. The general configuration of the pole pieces and arrangements for exposure of experimental material are indicated in Figure 1a. The pole pieces A and B are permanent, but C and D are adjustable and when in place enable one to secure maximum field strength between their tips. In Figure 1b a muscle M lies to the left of the poles C and D, and the nerve N to the muscle passes between the pole tips through a gap 1 mm. in width.

Field strengths were measured by means of a bismuth spiral. Table 1 indicates the field strengths at points 1 to 10 in Figure 1a with pole pieces C and D in position and with different amperages. The breadth of the most intense field with its center at point 1, immediately between the tips of the pole pieces, is indicated in Table 2.

Two general types of experimental exposure were employed. In the first of these, blood and isolated nerve-muscle preparations were exposed to the greatest field strengths obtainable, such fields obviously requiring use of the magnet under large amperages with the pole pieces C and D in position. By reference to the positions covered in Tables 1 and 2, one can readily arrive at a close approximation of the conditions to which the tissues were subjected. For example, if a nerve-muscle preparation is placed in a moist chamber K of Figure 1b with the nerve crossing the small gap between C and D, it is clear that the nerve impulse set up at the tips of electrodes E and F and passing along the nerve to the

muscle must, if the magnet is activated by a current of 20 amperes, pass a field intensity of 18,725 c.g.s. lines per square centimeter (Table 1), and that the field strengths to which all parts of the preparation are exposed may be told provided the lengths of the muscle and the nerve are known.

The second type of experimental exposure required the use of entire animals and is described in detail in a later section of this paper. To provide room for these exposures C and D were removed, leaving a large gap, 12 inches by 18 inches. Under these conditions the field strengths obtainable varied in different parts of the gap. Table 3 gives the field intensities at 15 amperes through the center of this field and indicates in an approximate manner the conditions to which animals were subjected over a considerable time.

b. Nerve-Muscle Experiments. — Since the nerve, when it conducts an impulse, exhibits an electrical change, and since a similar change occurs in muscle just prior to actual contraction, we examined carefully to see whether nerve conduction or muscular contraction suffered as a result of exposure to the strong magnetic fields we could supply. Various types of experiment were employed, the ordinary nerve-muscle preparation of the frog and the nerve of the cat being the test objects used. Several examples will suffice to indicate the innocuous character of the field.

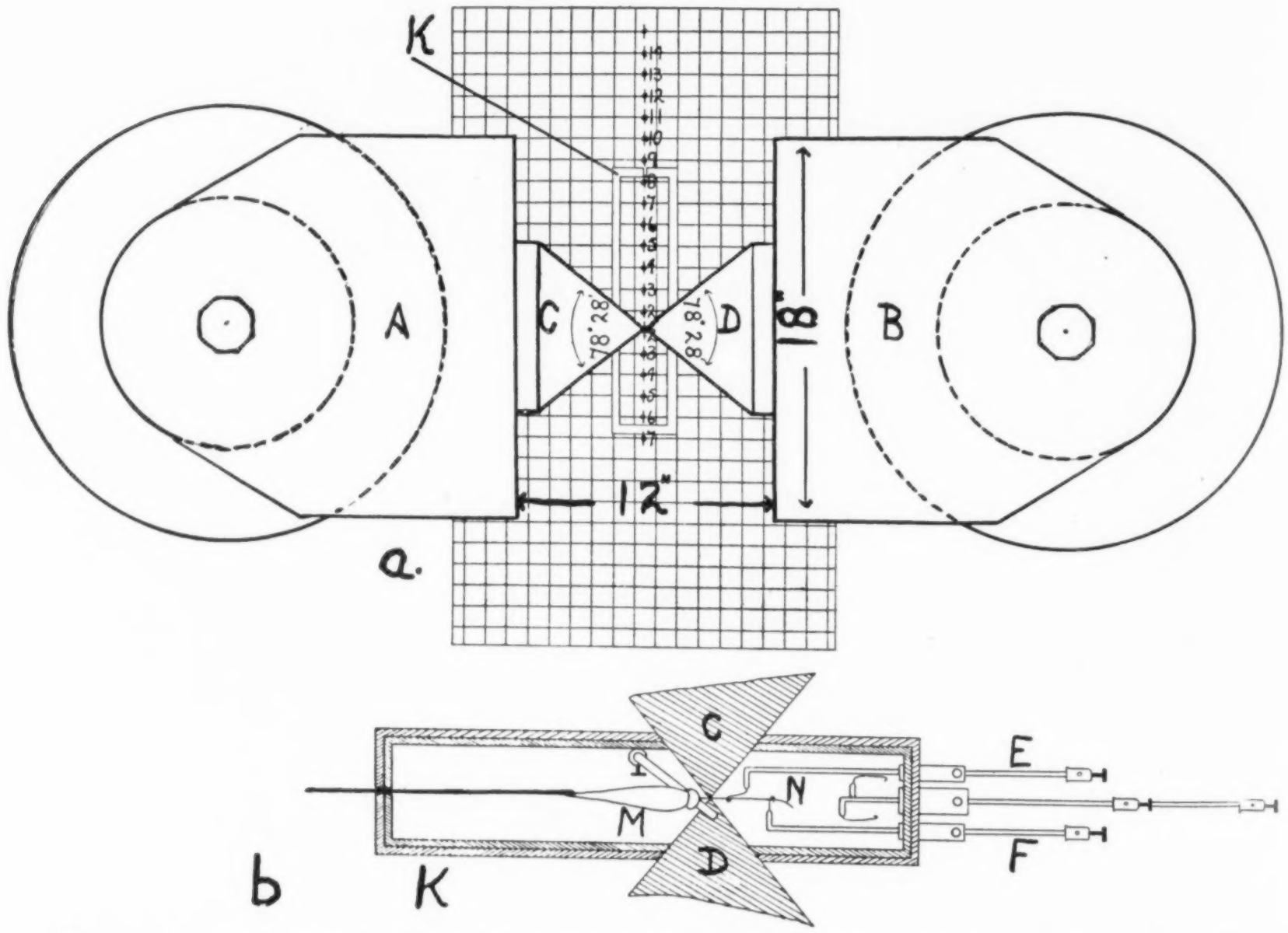


FIG. 1a. — Arrangement of pole pieces A and B, and C and D, with moist chamber K in place. The positions at which magnetic field strengths were determined are indicated by numbers down the center of the field.

b. — Arrangement of nerve-muscle preparation in moist chamber K. M indicates muscle; N, nerve; E and F, stimulating electrodes.

Jan. 27, 1919. — Two nerve-muscle preparations (sciatic-gastrocnemius) were made from the same frog. One of these was placed in a moist chamber (Figure 1b) fitted about the pole pieces C and D, which had been lightly coated with paraffin, with

the nerve on electrodes E and F and the muscle clamped in the position shown. From the tendon of the muscle a light silk thread passed out of the moist chamber to a muscle lever lightly weighted and adjusted to write on a large kymograph. The electrodes to the two nerves connected in series in the secondary circuit of an induction coil. The steadiness of the current used in stimulation was controlled by the employment of a milliammeter in the primary circuit of this coil. The thresh-

TABLE 1.—MAGNETIC FIELD STRENGTHS IN C. G. S. LINES PER SQUARE CENTIMETER AT VARYING AMPERAGES IN POSITIONS 1 TO 10, FIGURE 1a, POLE PIECES C AND D IN POSITION

Amperage	Field Strengths in C. G. S. Lines in Positions									
	1	2	3	4	5	6	7	8	9	10
10	17,450	8,150	4,825	3,500	2,775	2,400	2,100	1,975	1,825	1,750
15	18,375	....	....	....	....	....	....	....	....	....
20	18,725	9,200	5,425	3,900	3,175	2,650	2,375	2,325	1,900	1,800
22	18,975	....	....	....	....	....	....	....	....	....

TABLE 2.—MAGNETIC FIELD STRENGTHS IN C. G. S. LINES PER SQUARE CENTIMETER IMMEDIATELY IN VICINITY OF POLE TIPS C AND D AT TWO AMPERAGES, SHOWING DETAILS OF FIELD STRENGTH DECREASE BETWEEN POSITIONS 1 AND 2

Amperage	Field Strengths in C. G. S. Lines in Positions [1]					
	1	1a	1b	1c	1d	2
10	17,450	16,375	12,750	10,100	8,400	8,150
20	18,725	17,950	14,200	12,075	9,625	9,200

[1] Distance between 1 and 1a = 0.25 inches
" " 1a and 1b = 0.25 "
" " 1b and 1c = 0.25 "
Distance between 1c and 1d = 0.25 inches
" " 1d and 2 = 0.125 "
" " 1 and 2 = 1.125 "

TABLE 3.—FIELD STRENGTHS IN C. G. S. LINES PER SQUARE CENTIMETER WITH POLE PIECES C AND D REMOVED

Amperage	Field Strengths in C. G. S. Lines in Positions									
	1	2	3	4	5	6	7	8	9	10
15	2,800	2,800	2,825	2,825	2,825	2,825	2,800	2,725	2,600	2,400

control muscle was placed in a second chamber lacking the orifices for the pole pieces C and D but in other respects entirely similar, and through a similar muscle lever was caused to write upon the kymograph just above the lever recording the magnetic field muscle. Tight-fitting lids were placed on both chambers and the old stimulus for both preparations was then obtainable by breaking the primary circuit while bringing the secondary coil toward the primary. With the first contraction of the muscles the position of the secondary coil was read, and this represented the minimal or threshold stimulus. Further approximation of the secondary

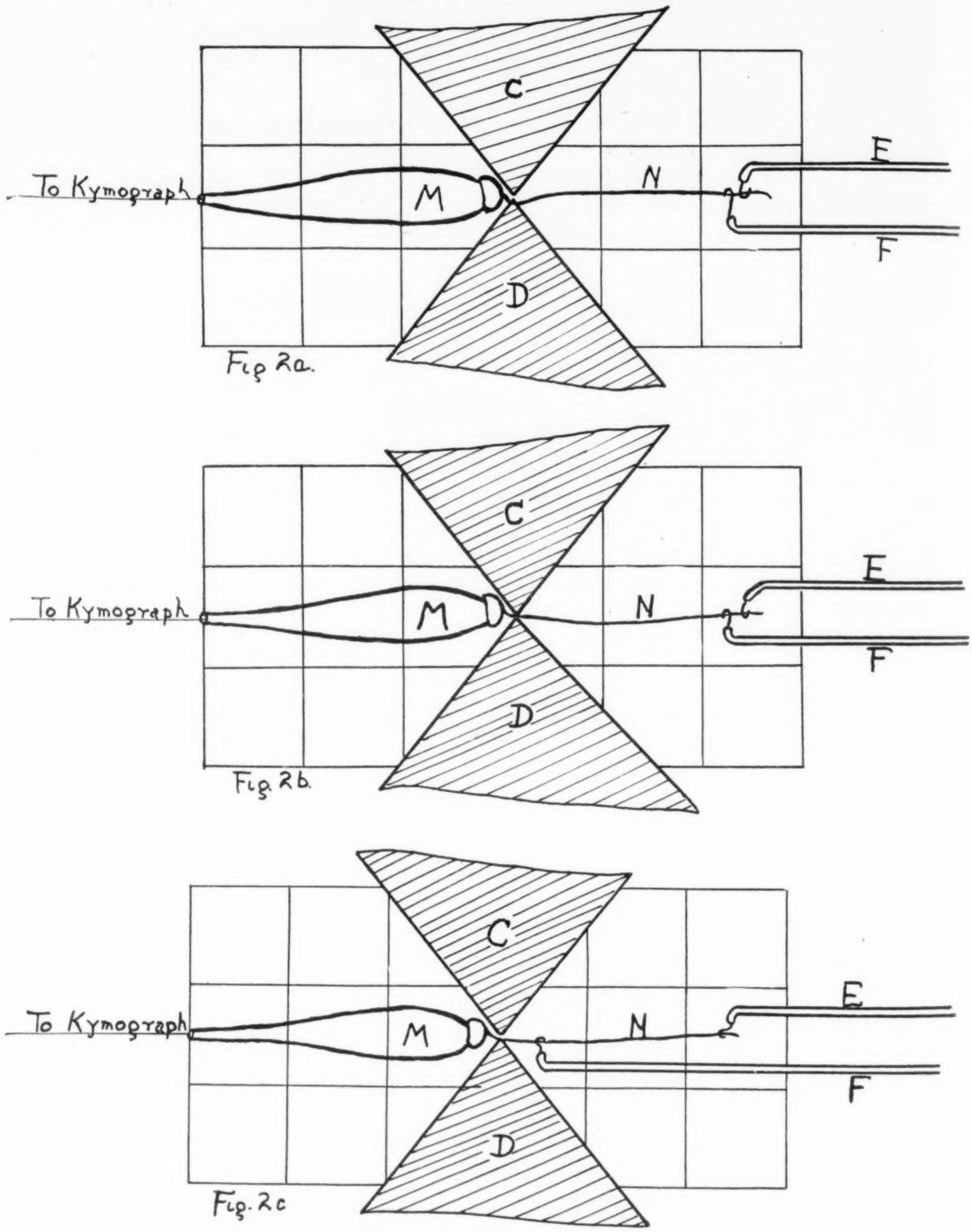


Fig 2a.

Fig. 2b.

Fig. 2c

FIG. 2a. — Experiment of Jan. 27, 1919, showing position of nerve N, muscle M, and pole pieces C and D. Electrodes 3½ mm. apart, at a position between 3 and 4; gastrocnemius tendon at 4; and body of muscle between 4 and 1.

b. — Position of nerve after experiment had been in progress four hours.

c. — Position of stimulating electrodes for the last eight hours of the experiment.

coil increased the strength of stimulus and by this means the maximum response was rapidly obtained.

Figure 2a gives the positions of the nerve, the muscle, the stimulating electrodes, and the pole pieces of the magnet in terms of the positions in Table 1. Figure 2b shows a slight variation caused by movement of the nerve during the experiment, and Figure 2c, the final position of the stimulating electrodes. In all cases the positions of the electrodes on the nerve were duplicated in the control preparation.

Figure 3 (p. 127) shows a series of contractions taken simultaneously under identical strengths and conditions of stimulation during the experiment of Jan. 27, 1919. The results of this experiment are summarized in Table 4.

Reference to Table 1 and to Figures 2a, 2b, and 2c will show that the nerve at the original point of stimulation experienced a magnetic field intensity varying between 5,425 and 3,500 c.g.s. lines per square centimeter, that the nerve impulse to reach the muscle had to cross a field of 18,725 to 17,450 c.g.s. lines per square centimeter, and that the contracting muscle lay in a field varying between 18,725 and 3,500 c.g.s. lines per square centimeter. The total period of exposure was from 11.46 A.M. to 5.29 P.M. on the next day, or twenty-nine hours and forty-three minutes. During this period the threshold for conduction of the nervous impulse was tested 116 times and, although the nerve exposed to the magnetic field ceased to conduct before the control, the difference is of no consequence in the face of such a long period of survival. It will be noticed by reference to

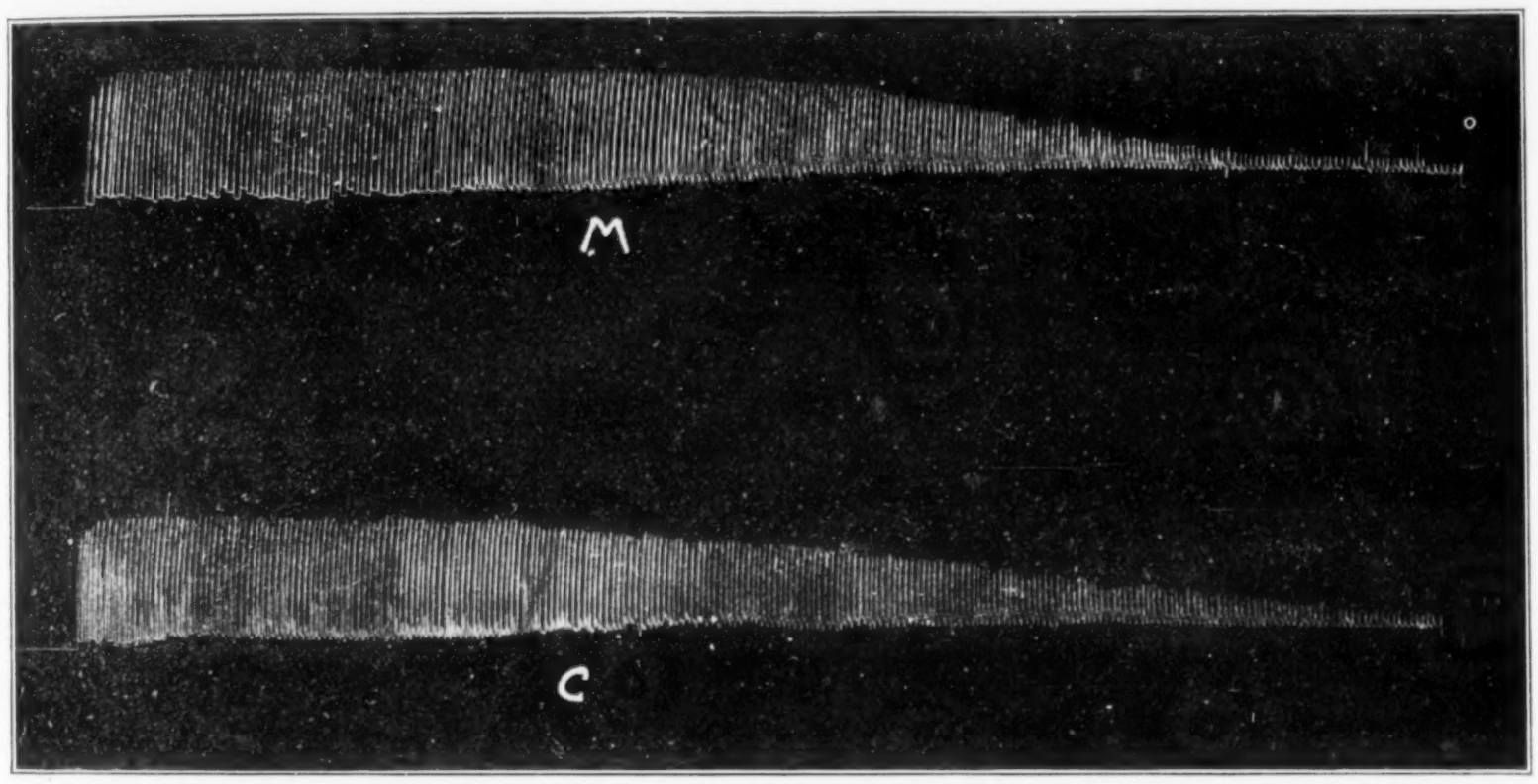
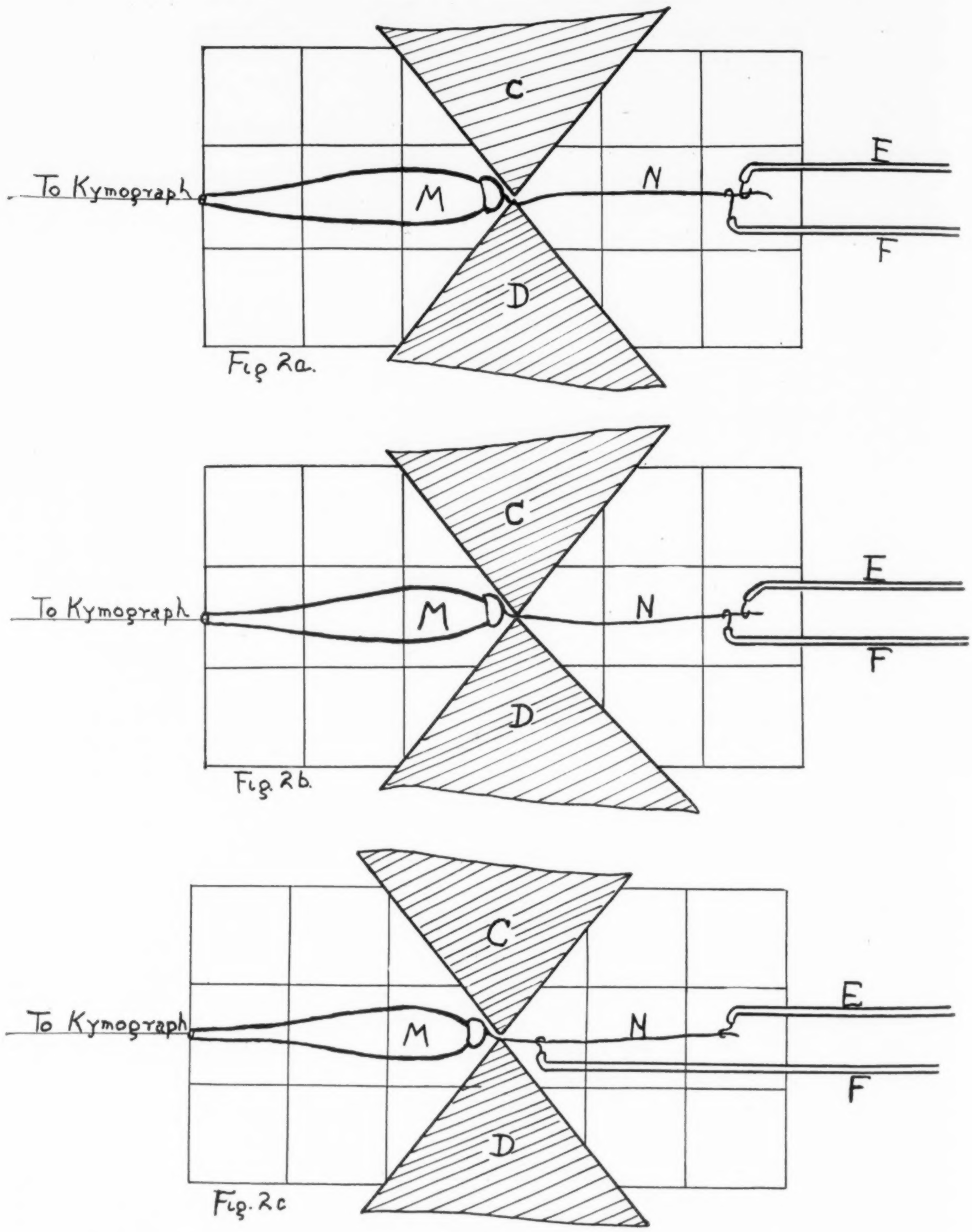


FIG. 4. — Fatigue curves written by companion nerve-muscle preparations under identical conditions of stimulation. C indicates control muscle; M, muscle exposed to magnetic field.

49 and 50, Figure 3, that at the end of the first twenty-one hours and before the stimulating electrodes were moved the preparation which had been in the magnetic field was in better condition than the control. When the electrodes were moved a difference in behavior resulted, but throughout the experiment the entire course of events was not different from that obtained when two nerve-muscle preparations are set up under identical conditions. In order to be entirely sure that this interpretation was correct the experiment was repeated eighteen times, but no trace of magnetic field effect was ever obtained.

A second type of experiment is illustrated in Figure 4. In this case two nerve-muscle preparations were set up as in the



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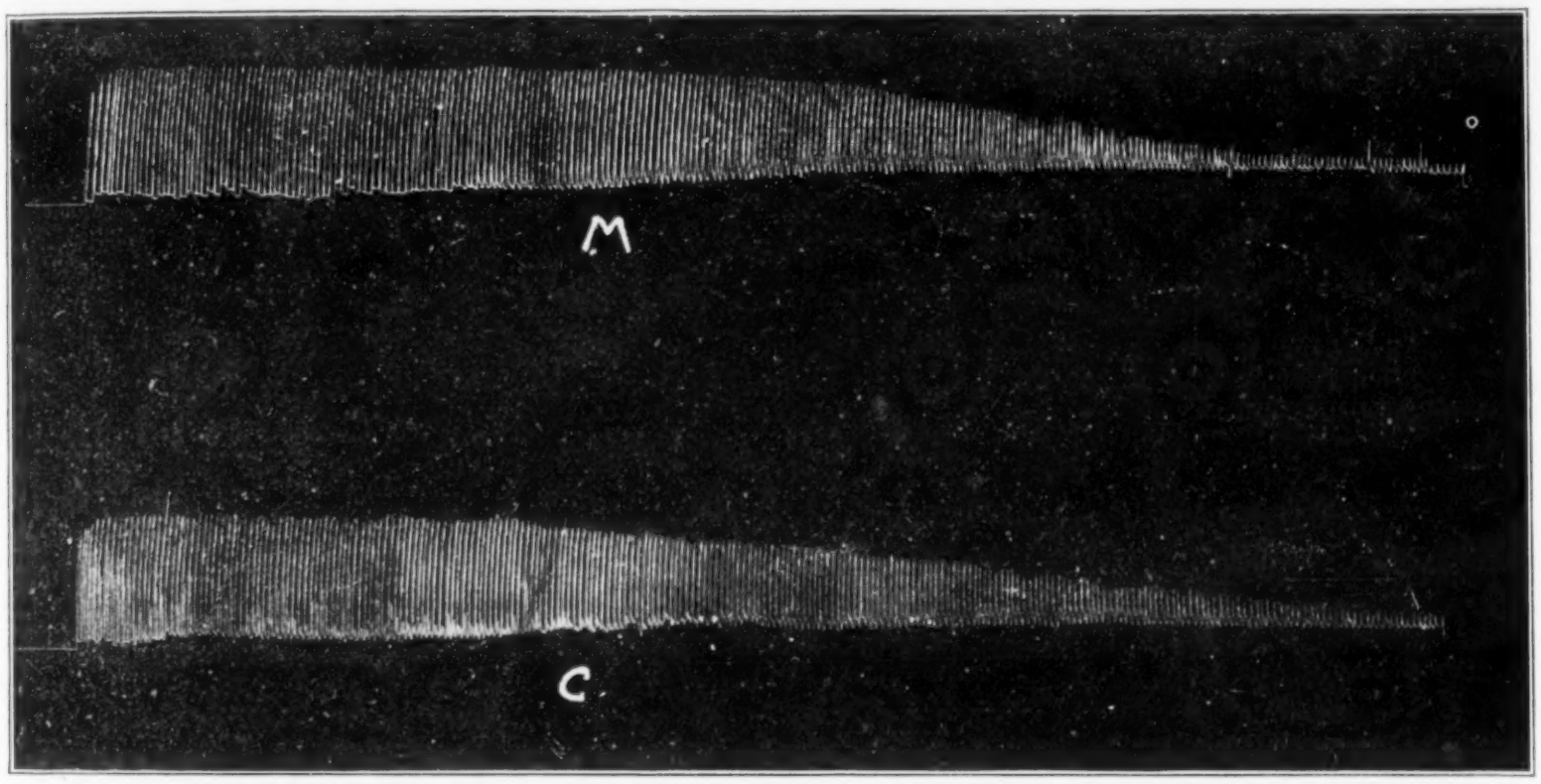

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TABLE 4. — THRESHOLD STIMULI OF MAGNETIC FIELD AND CONTROL MUSCLES DURING THIRTY HOURS

Time	Temperature	Current in Primary Circuit Inductorium	Magnet Circuit	Observation No.	Threshold Stimulus in Scale Divisions	
					Magnetic Field Muscle	Control Muscle
January 27 *A.M.*	*°C*	*Amperes*	*Amperes*			
11.30–11.32	17.2	0.075	...	1	21.0	29.0
11.44–11.46	...	0.075	...	2	21.5	28.0
11.46 [1]	...	...	20.4	...	...	...
11.51–11.53	17.0	0.075	...	4	21.0	29.0
11.58–12.00	...	0.072	...	5	21.0	28.0
P.M.						
1.48	...	...	18.6	...	...	...
2.56–2.58	...	0.072	...	30	20.0	26.5
3.11–3.13	...	0.072	...	31	20.5	26.5
3.27	...	...	18.6	...	...	...
4.10	...	...	18.6	...	...	...
4.59	...	...	18.2	...	...	...
5.18–5.20	...	...	...	49	19.0	23.0
5.25–5.27	...	...	...	50	19.5	24.0
5.27 [2]	...	...	10.0	...	...	...
January 28 *A.M.*						
8.47	...	...	15.0	...	...	...
8.47–8.49 [3]	12.2	0.069	...	51	6.5	No contraction obtainable.
10.07	...	...	19.2	...	...	...
10.47	...	...	18.9	...	...	...
P.M.						
1.28	...	...	18.4	...	...	...
2.07–2.09	...	0.072	...	95	9.5	10.0
2.14–2.16	...	0.072	...	96	9.5	10.0
2.30	...	....	18.2	...	...	...
3.52–3.55	...	0.072	...	109	7.5	9.5
4.00–4.02	...	0.072	...	110	7.0	9.5
4.52	...	...	18.0	...	...	...
5.20–5.22	...	0.072	...	120	3.0	8.0
5.27–5.29	...	0.072	...	121	3.0	7.5

[1] Magnet turned on.

[2] Magnet circuit reduced to 10 amperes and left for night.

[3] Magnetic field muscle continued to show threshold at 6 until 9.40 when it became impossible to obtain contraction even with maximum stimuli. Electrodes on both nerves were accordingly moved into the positions indicated in 2c. Both nerves were slowly drying in spite of moist chamber conditions.

previous experiment and were compelled to contract repeatedly, lifting each time a 70-gram weight and registering their work through two similar work-adders. In this particular instance the belly of the muscle subjected to the magnetic field was placed immediately above the pole tips C and D and the magnet was held at 20 amperes. The muscle, therefore, was subjected to a field intensity of approximately 17,950 c.g.s. lines per square centimeter (Table 2). In this experiment the tracings written by the control C and the magnetic field muscle M are practically identical, the work done by the control being 2,856 gm. cm., and by the magnetic field preparation 2,639 gm.

cm. Such results fall within the limits of error in comparisons of two normal muscles and indicate no harmful effect from the magnet. The same experiment repeated ten times never gave evidence of any action whatsoever on the part of the magnetic field.

Figure 5 displays fatigue curves made by two companion isolated muscle preparations stimulated directly, the electrodes in each case being placed in the capsule of the knee-joint and in the gastrocnemius tendon. During the period of work muscle M was subjected to a magnetic field of approximately 17,950 c.g.s. lines per square centimeter, the belly of the muscle lying just above the tips of the poles C and D. In this case the control muscle C did 3,444 gm. cm. of work against 3,668 gm. cm. for the muscle exposed to the magnetic field.

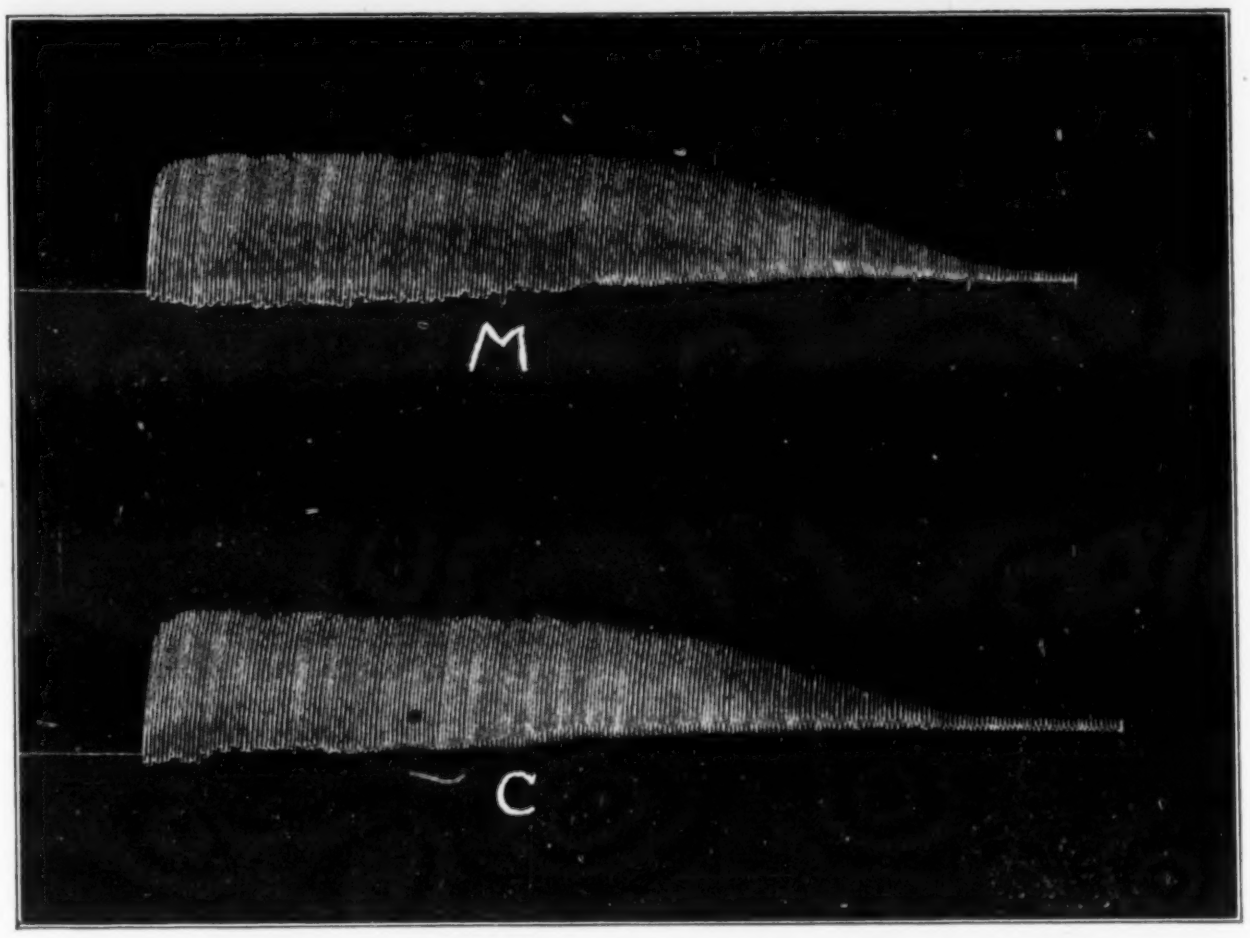

FIG. 5. — Fatigue curves written by companion gastrocnemii muscles under identical conditions of stimulation. C indicates control muscle; M, muscle exposed to magnetic field.

Omitting details of other experiments, we may sum up our results by saying that in isolated nerve-muscle preparations we have never been able to observe any change in irritability or conductivity of nerve nor in the contractile power of muscle as a result of exposure to the magnetic field.

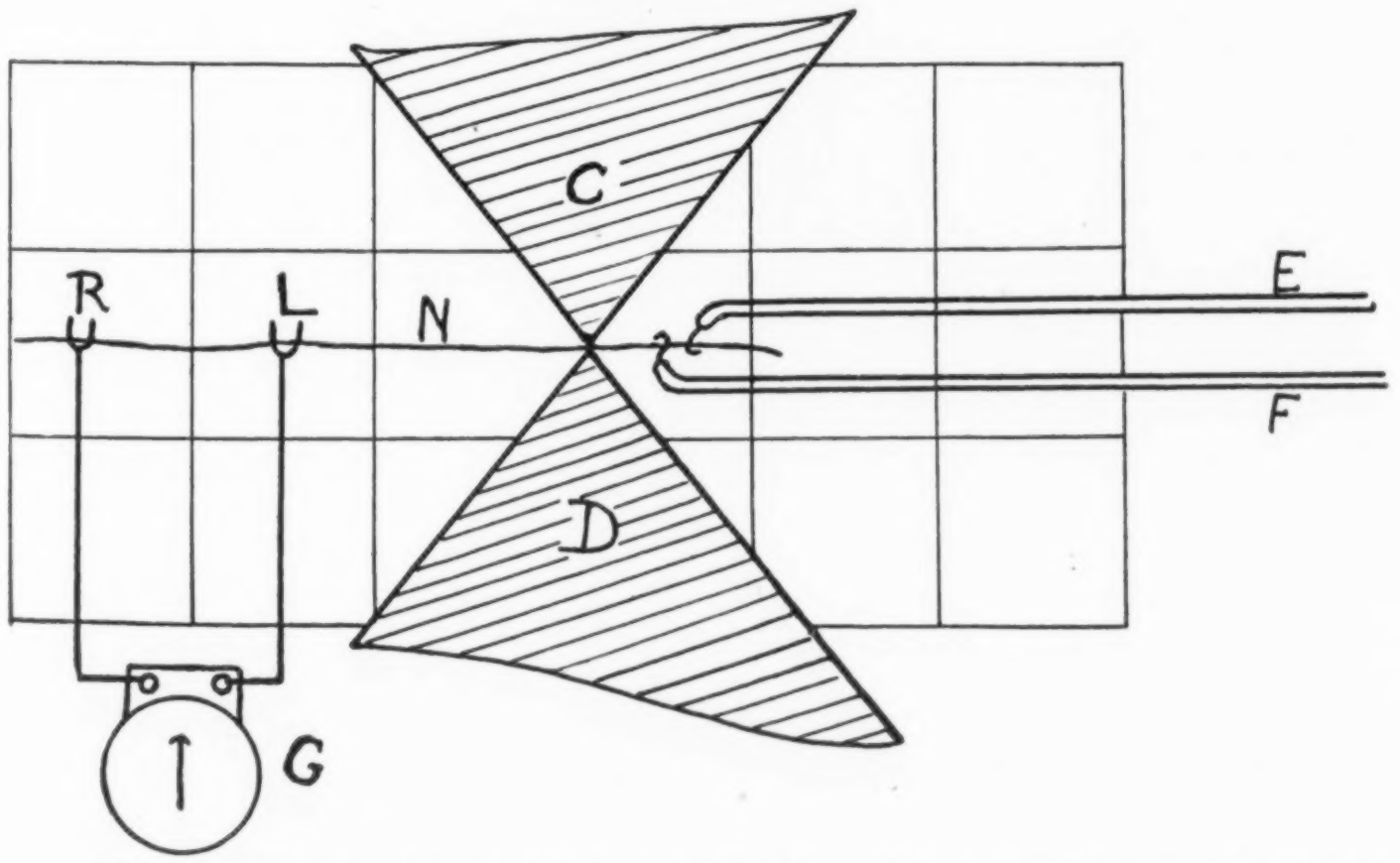

FIG. 6. — Diagram of apparatus for recording the action current of mammalian nerve. E and F indicate stimulating electrodes; C and D, pole pieces of magnet; L and R, non-polarizable electrodes leading to the string galvanometer G.

As a final experiment to test the effect of the field upon the nerve impulse we placed a long section of cat nerve (popliteal) in a moist chamber under the conditions given in the diagram, Figure 6, in which E and F are the stimulating electrodes and L and R leading off electrodes to a string galvanometer.* Figure 7a is a photographic

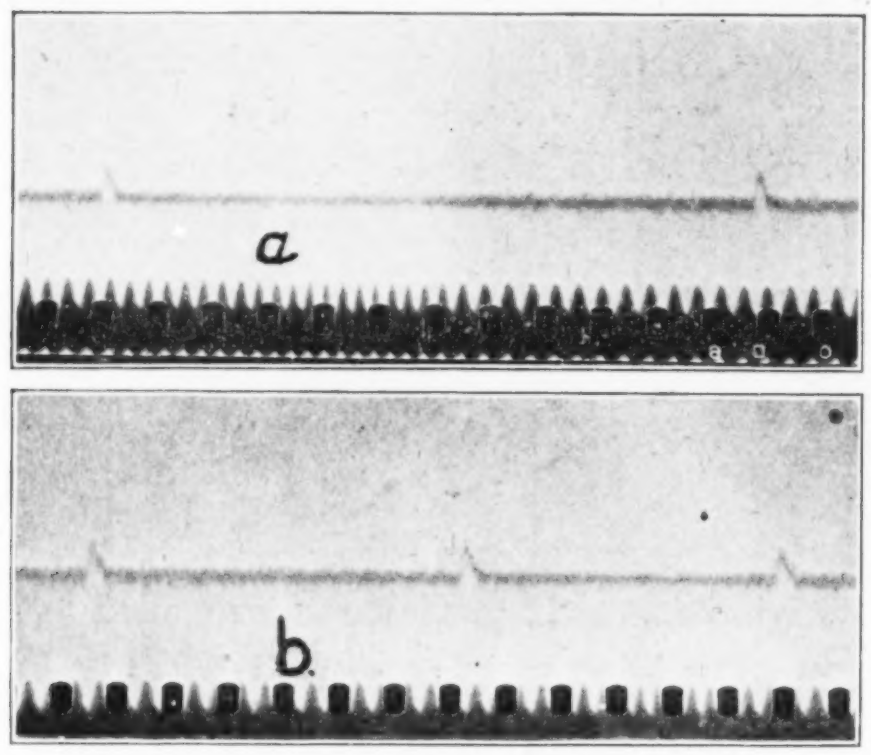

FIG. 7a. — Action current of popliteal nerves prior to exposure to magnetic field.

b. — Action current of same nerve after two and one-half hours of exposure to a field of 18,725 c.g.s. lines per square centimeter.

record of the action current of this nerve prior to magnetic field exposure, and Figure 7b a record of its action current after two and one-half hours' exposure to a field of 18,725 c.g.s. lines per square centimeter. As this record shows, the magnetic field produced no change in the action current which signals the passing of the nerve impulse.

In addition to these experiments with isolated nerve and muscle, a certain number of experiments were done with red blood corpuscles and blood. It was shown that prolonged exposure (two and one-half hours) to magnetic fields of 18,725 to 14,200 c.g.s. lines per square centimeter had no effect upon the shape of red blood corpuscles nor upon their oxygen combining power. In the same strengths and conditions of exposure complement and hemolytic amboceptors were likewise unaffected.†

c. Experiments upon Animals. — The exposure of living animals to magnetic fields for short periods of time and under a considerable degree of restraint is easily arranged, but, feeling that such a procedure gave little promise of interpretable results, we endeavored to find small animals of active type — certain to make natural movements in the field — and to expose them under circumstances permitting constant observation of their condition. Dancing mice were finally selected as the mammal most suitable for the experiment.

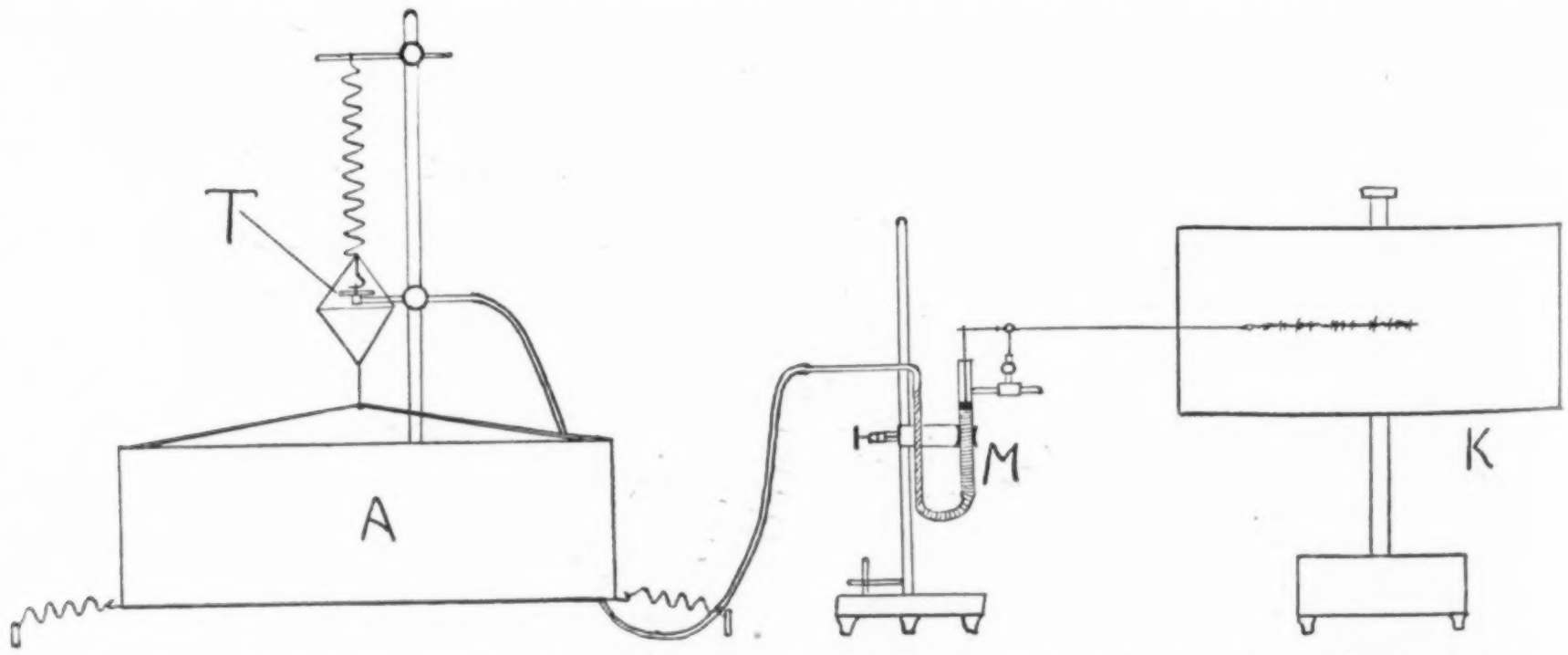

FIG. 8. — Diagram of apparatus for exposing dancing mice to magnetic field. A indicates aluminum box; M, manometer; K, kymograph; T, tambour.

* The observations involving the string galvanometer were made for us by Dr. Alexander Forbes.

† For these last observations we wish to express our thanks to Dr. A. Watson Sellards.

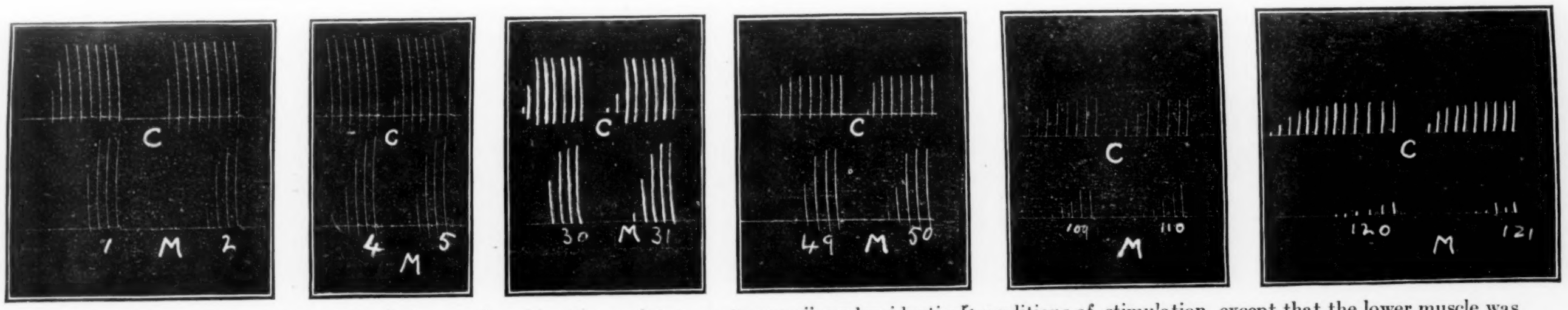

FIG. 3. — Tracings showing the single muscle contractions of two gastrocnemii under identical conditions of stimulation, except that the lower muscle was contracting in a strong magnetic field.

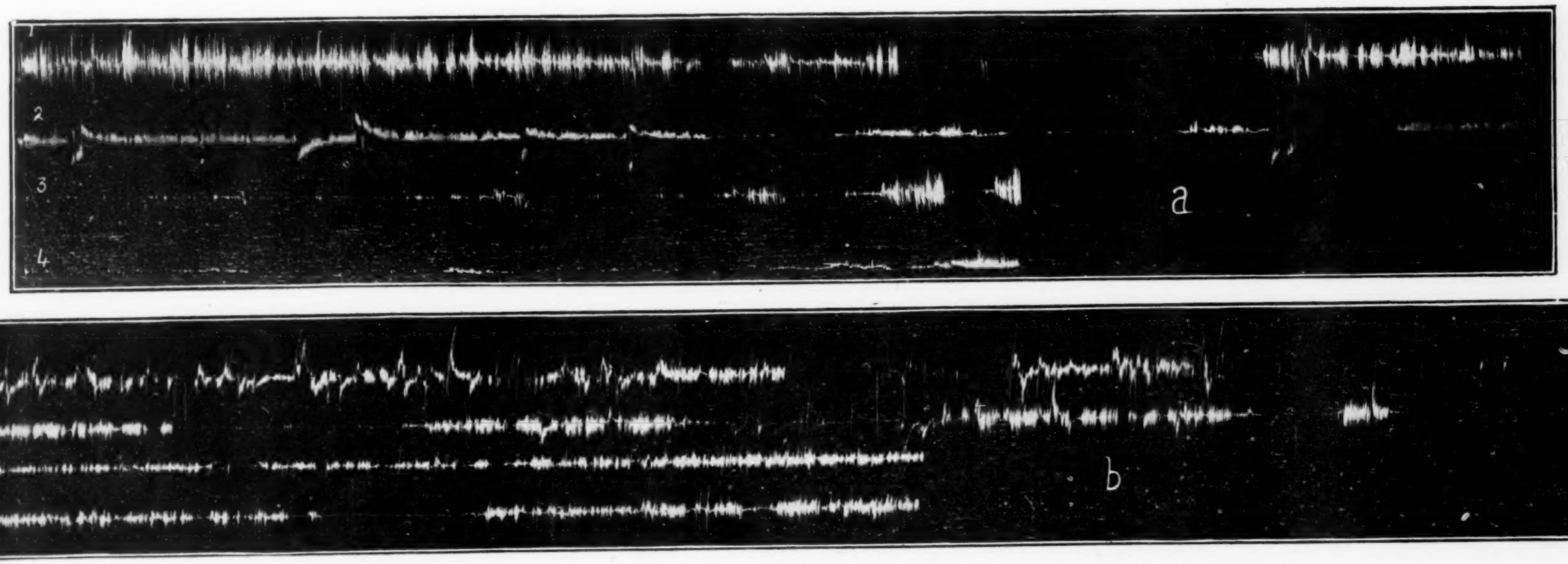

FIG. 9a. — Tracings indicating the activities of two pairs of mice placed in aluminum boxes such as the one diagrammed in Figure 8.
b. — Tracings from the same animals three months later; 3 is the day record for the mice exposed to the magnetic field, and 1 the night record for the same pair.

These animals are small, active, and easily cared for during a protracted experiment. Accordingly, we exposed dancing mice in pairs to magnetic fields, the strengths of which are given in Table 3.

Figure 8 indicates the manner in which these animals were studied. An aluminum box A, 6 by 12 inches, served as a cage for a pair of mice. This box was suspended by a light brass spring adjusted to a tambour T so that every movement of A acted upon the rubber diaphragm in T and by air transmission activated the oil manometer M which wrote upon a slowly moving kymograph K. The box A was lightly anchored at the corners by brass springs and fitted into the large gap in the magnet, secured by removing pole pieces C and D. A control pair of mice occupied a second box, their movements being recorded upon the same kymograph through exactly similar devices. Mice lived in the box A for periods of three months, being exposed to fields of approximately 2,800 c.g.s. lines per square centimeter for an average of fifteen hours daily during this period. The magnet was turned on when we left work in the evening and turned off next morning in order to avoid the annoyance of having it active during working hours in the laboratory. The life of the mice during periods of this sort was apparently entirely normal. Females became pregnant, and when killed near term were found to contain normal young. No signs of disease were observed. The mice continued sound during the experiment and their organs, when examined microscopically at the close of the experiments, were found to be normal.

In Figure 9a we have a record covering a twenty-four-hour day for the control pair of mice and for the pair exposed to the magnetic field. The two lower lines of tracing represent the movements of the pairs of animals in their cages during the day period, and the two upper longer lines, the activity during the night. Figure 9b shows a similar set of tracings upon the same pairs of mice after three months' exposure of one pair to the magnetic field. The top and third from the top tracings are those for the magnetic field mice and show a normal degree of activity.

As a final type of experiment we frequently placed our own heads in magnetic fields of as great strengths as were obtainable, but were never able to appreciate any effect whatsoever — a result which corroborates the findings of Peterson and Kennelly (4). With the magnet which we used the effects of alternating currents could not be tested, and we are, therefore, not in a position to speak upon this phase of the subject.

Conclusions

1. The effect of constant magnetic fields varying between 18,725 and 2,800 c.g.s. lines per square centimeter has been studied in experiments upon various types of nervous and muscular tissue, upon blood, and upon intact animals.

2. None of these experiments has given the slightest evidence of physiological effects from the magnetic field.

3. The experiments cited have utilized field strengths far greater than those to which workmen are subjected, and, since the tissues employed were those most likely to show vulnerability, it seems certain that the magnetic field has no significance as a health hazard.

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THE INDUSTRIAL PHYSICIAN AND THE QUALIFICATIONS ESSENTIAL TO HIS SUCCESS *

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OF all the specialties in the medical field, perhaps the one which is least understood is that of the industrial physician. To emphasize the importance of this specialty, we have but to recall some instances of the past. We are more or less familiar with the disastrous effect, during the war, of the manufacture of the explosive, trinitrotoluene, resulting in fatal cases of toxic jaundice, as described in the report of the Ministry of Munitions, London. Previously, this substance had hardly been regarded as toxic; but when the necessity arose to manufacture it in large quantities, and at a time when the conservation of the life and health of the worker was of the utmost import, mortality from its poisonous effects became alarming. Had it not been for the preventive measures instituted by a few men with training in the hazards of industry, based on previous knowledge and experience of the nearest analogies, the mortality from this poisoning would have been markedly increased; and had this branch of medicine been developed equally with other specialties, one is justified in believing that the mortality not only from T.N.T. poisoning but from the large list of other recognizable hazards would have been appreciably lowered.

The trend of modern thought is toward conserving and preserving human life. Science functions at its best when it conquers disease and reduces the hazards of human existence. Industrial hygiene shares its place with other welfare organizations designed to give the youth of the nation a chance to develop mentally and physically, to keep the body strong and well and fitted for the tasks and duties of the day, and to live long and useful lives. Millions of dollars are spent, and justly so, in the control and prevention of disease, in providing pure drinking water and food products from healthy stock, and in educating the public in health matters. Yet, little indeed is to be gained by these activities and by the expending of additional enormous sums of money in the rearing and education of children, and in the promotion of their health, if their lives, at the prime, are only to be crushed out by the unnecessary hazards of industry.

Oliver (1) speaks of lads under 18 years of age who were given employment where the lead hazard existed. "These youths," he says, "all of good physique, well-developed and healthy looking, were examined medically before entering the factory, and yet, notwithstanding this precaution, so great was the amount of lead poisoning amongst them, and in such a short time, too, that the employers were obliged to dismiss them." In recent years, however, much has been accomplished, both in foreign countries and in America, toward eliminating this hazard which is perhaps the greatest of all industrial hazards, and which at one time was present in about 150 different industries. But the hazards with which the industrial physician must cope are still many and require constant vigilance.

Throughout every state and virtually every community in this country costly machinery is installed and maintained at a high degree of efficiency, for the purpose of increasing production. Aside from purely humanitarian views, if we conceive of the workman as a factor in production, we are

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in him dealing with the most potentially efficient machine in the universe.

M. Amar (2) describes the human motor as probably an "electro-capillary" engine, the nature of the nervous agent and the origin of human power being, however, unknown. Man's power is approximately 1–7 H.P., but the efficiency is about 30 per cent., or very high. Compared to a steam engine, the human motor performs its work on half the fuel consumption. The life of the human motor is greater than that of any inanimate prime mover, which is placed at a maximum of 20 years unless frequently repaired. Till old age sets in, the human motor is self-repairing. Its control is internal. In general:

"The maintenance of the human machine is as difficult and important a matter as the maintenance of any inorganic motor. We must do our best to eliminate all internal and external conditions tending to cause depreciation. Especially must physiological discomfort be avoided and removed, as far as possible. In the due proportion of effort and speed, in industrial labor, lies the key to intensive production and the well-being of the workman."

The uninitiated may marvel that a science should exist for the purpose of increasing human efficiency and decreasing waste; yet it is only by the application of the scientific principles of industrial hygiene and sanitation that a man can produce an increased yield sufficient to justify a larger compensation for his labor, and can thus be enabled to live in comfort and to find new strength and enjoyment in his work each day. It is, therefore, of vital import that the public at large should be interested in those conditions which materially affect the health and welfare of approximately one-third of the population of enlightened countries — namely, the producers of the world. To accomplish constructive improvements, organization of interests and co-operation with other sciences are essential; but as the human factor, with which the physician has to deal, is the greatest of all factors in the activities of life, all other factors should revolve around it as a center.

Unfortunately, the term "industrial physician" has been erroneously applied to general practitioners who spend part time in treating cases of sickness and injury sent to them from industrial plants. Even contract physicians have been at times classified under the same head. The restricted conception of the industrial physician limits the appellation to the man who has specialized in the field indicated in this paper. He is no longer the practising physician who makes an hourly trip to the plant in order to dress minor injuries, or who is called when a worker suddenly becomes ill or is hurt. On the contrary, he is a trained specialist in industrial hygiene and occupational diseases, and does not engage in the general practice of medicine nor of surgery any more than does the specialist in other branches of medicine.

It is true that little opportunity is offered the industrial physician to prepare for his specialty, and he must of necessity accumulate his knowledge from promiscuous sources. An attempt has been made to merge this all-important specialty, as a branch, with preventive medicine or social medicine, but the field of industrial hygiene and sanitation is sufficiently broad and sufficiently well defined to constitute in itself a specialty, and the demand for trained men is imperative. A few medical schools are now recognizing the importance of training men for this work and are offering special courses for it. Much remains to be accomplished in this direction, however, and a more comprehensive course including actual field work is desirable.

Diagnosis of ordinary occupational diseases is, to be sure, not difficult, but early recognition of them, which is all important, is quite so. It is unfortunate that the industrial physician must for the most part recognize the early diagnostic symptoms of many industrial diseases through experience and from the perusal of special articles, for the reason that textbooks usually emphasize only the more advanced symptoms. It is obvious, therefore, that

to become qualified for his task, the industrial physician must have special training and special qualifications as well.

In the first place, the question arises as to the specific position of the industrial physician in industry — whether he serves the employees or those who employ him. The physician who serves either to the exclusion of the other fails in the high purpose of his mission. I know of physicians who are employed mainly for the protection of the management against lawsuits, and who are expected, no matter what the cause of the ailment or injury, to convince the patient that his trouble is the result of his own carelessness and is in no way caused by his working conditions. Such policies among physicians are soon recognized by employees, and have a tendency to cause them to resent, and with some degree of right, the aid offered them by fair and conscientious physicians.

The task of the industrial physician is by no means easy. He occupies the position of *liaison*, as it were, between management and employees. His duties toward the former are to increase the efficiency of the workers, in order to secure and maintain a high rate of production; to prevent wastage; to minimize labor turnover; and to interpret the workers to the management, by pointing out causes of dissatisfaction among them and suggesting remedies for it. His duties toward the employees are to promote health, sanitation, personal hygiene, and contentment; to maintain cleanliness and order; to lessen the possibility of accidents and disease; to protect against dust, industrial poisons, inadequate ventilation and illumination, over-fatigue, draught, extremes of heat and cold, danger of fire; to advise in the selection of jobs suitable to the physical capacity of individuals; to improve the morale; and to interpret the management to the workers.

In order to accomplish these ends, the industrial physician should be characterized first of all by fairness, tactfulness, and a sympathetic attitude, which will enable him to secure effective co-operation. He must evaluate statements of both employer and employed; must discriminate between facts, opinions, bias, and prejudice, through observation of actual conditions; and wherever possible must base his judgment upon facts instead of upon opinions.

In making the initial physical examination of the worker, the physician should be guided by the mental as well as the physical fitness of the individual, and should assist the management in hiring advantageously and in giving each new man such work as he can best perform. When we consider the fact that, as measured by mentality tests, the greater number of men in the army were of average or less than average intelligence — which is probably true today of the men of the country as a whole — it is evident that, in spite of some limitations, each man according to his grade of mentality and intelligence may be assigned a part in the whole organization that will lead to his success and happiness.

Again, the ability of the industrial physician and his value to industry are measured largely by his knowledge of and familiarity with the needs of the plant. Before he can recommend or even suggest changes for improvement, he must have at least a working knowledge of the materials used, the products and by-products manufactured, the processes involved, and the possible hazards existing.

The industrial physician's first duty on assignment to any plant is to make a comprehensive survey of conditions, including an analysis of each department into its various jobs and a study of the processes of each. The paramount idea of such a survey is "seeing with trained eyes" and utilizing the collected facts to establish a basis for recommendations. No alteration or improvement should be recommended without sufficient reason, and the physician

should guard against staggering the management with recommendations requiring large expenditures of money. A survey likewise fails if the investigator is unable to interpret his findings.

It may be well to review briefly the most important factors which may constitute hazards in industry and which are of interest to the industrial physician. Let us first consider the subject of ventilation. While the task of providing adequate ventilation in the larger plants is the duty of a ventilating engineer, the maintenance of the ventilation system and, in some instances, the installation of the system rest upon the industrial physician. The essential factors to be considered in ventilation are temperature, degree of moisture, and air movement. The air may be vitiated by impurities which arise from manufacturing processes, from floors of the rooms, from persons, from lights burning, and from accidental sources, such as effluvia from drains, escape of gas, or impure outside air. The industrial physician should know the composition of pure air, and its value. He should be familiar with methods of removing impurities, pollution, dust, and dampness of surrounding surfaces, and should see that there is sufficient cubic capacity, with absence of overcrowding, constant movement of the air, proper and rightly placed inlets and outlets for the air, cross-ventilation, and moderate temperature and humidity. The objectionable features of an inadequately ventilated room are more frequently thermal than chemical.

No less important is the problem of adequate illumination, and a thorough knowledge of the subject is particularly essential for the successful industrial physician. With proper illumination over the working areas, the safety and skill of the worker may be maintained at a high standard, and production increased in quantity and improved in quality. Distinction must be drawn in regard to illumination, surface brightness, and glare. The physician should not only be familiar with the unit of measure for general illumination and the methods employed to test it, but should also know the number of units necessary for the performance of different kinds of work. The effectiveness of illumination cannot always be measured in terms of the vertically downward component of the light as it is sometimes of advantage to light the work plane from the side. For larger plants, at least, the engineer should be consulted in order that the fundamental principles of effective illumination — sufficiency, continuity, and diffusion — may be fulfilled.

The problem of illumination is by no means solved simply by the installation of an efficient system. Indeed, the maintenance of the system is of equal importance, because frequently, through neglect of proper upkeep, one-half of the light which a system is capable of supplying may be lost to the worker. The change from sufficient to insufficient light is very gradual and is often overlooked. Dust and dirt accumulate slowly, reflectors break, ceilings become darkened by degrees, here and there is an empty socket or a lamp of incorrect voltage. Thus, it frequently happens that the cumulative effect of these needed repairs is noticed only after the workmen complain of eyestrain.

The proper method of using lighting equipment so that it may be suitable to the needs of a plant is as important as the wise choice of a system. Whether direct, indirect, or semi-indirect light is best, depends upon the purpose for which the light is to be used. It should also be remembered that faulty reflectors may do more harm than none at all.

That certain occupations are more fatiguing than others is common knowledge, and the physician is not interested in fatigue in the ordinary acceptation of the term; but he is deeply concerned with the effects

produced by over-fatigue, the boundary line between fatigue and over-fatigue, and the length of time necessary to recover from fatigue. There is no uniform method of treating this problem, and the physician must work it out to the best of his ability for each individual industry, for both sexes, and for different climates. Other problems, with which he is concerned and for which he should bear the responsibility, are personal service facilities, rest periods, welfare work, and effective methods of cleaning the plant.

As an aid in predicting the effects of certain reactions upon the worker, a knowledge of chemistry is of great advantage to the industrial physician, particularly as the substances used in industry are many and varied, and their effects multiple. For instance, it is an interesting fact that there are about 300 substances used in industry, which cause skin diseases and in dealing with which a knowledge of chemistry would clearly be exceedingly valuable.

Too much stress cannot be placed upon the importance of careful records. While it cannot be expected that every industrial physician should be a statistician, he should at least understand the fundamental principles of statistics, and if, in addition, he possesses the ability to interpret them accurately, it is a distinct asset to him. For record keeping, he should employ a standard form in general use, such as that suggested by the U. S. Public Health Service.

In conclusion, I wish to emphasize the value of the industrial physician in the mitigation of industrial unrest, which in large part is the reaction to unfavorable environment. Insanitary working conditions lower physical resistance; monotonous labor, discontentment, and continued long hours increase those physical defects which are soon acquired when resistance is lowered, and in turn the worker who has lost his former strength and vigor must accept lower wages, and poverty, with its many evils, is the result.

Diminished output is a danger sign of diminished physical energy. Desire to work cannot exist without good health. A healthy and contented laboring force is the greatest economic asset that capital can have, and such a force should be so protected and so guided that the greatest possible benefits may accrue to both employer and employee.

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AN INTERCHANGE OF PHYSICAL EXAMINATIONS IN INDUSTRY *

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A GREAT deal has been written concerning the many advantages of the compulsory physical examination in industry, but only once in a while is anything written — and then but a line or two — in regard to the objections that are advanced by the employer or the employee. The objections given by the employer are usually concerned with the cost of the service, while those of the employee are based upon some personal reason, such as his natural dislike for anything which he feels is being forced upon him and which may in some way abuse his private rights, or for any procedure which entails extra bother. Or perchance, as I have frequently known to be the case, he may object on the ground that he has recently been examined by a good doctor who said that he was all right, and therefore he does not care to be examined again.

We can oftentimes learn something from the other fellow even though his training may lead us to believe that he really has no right to an opinion on the subject in question, and I think that on the subject of compulsory physical examination, if we care to, we can undoubtedly learn something from our applicants. While for the most part compulsory physical examination is basically right, there are some respects in which it may be basically wrong, and it is on this side of the question that I wish to sermonize a little.

When an order is issued in an organization it is exactly comparable to an order in the regular army — it must be carried out, right or wrong. When it is ordered, however, that "Every man must have a complete physical examination before he can be given a job," the order is so general and so broad that it may easily include some things that are not right, and which give rise to unfortunate conditions, as I have witnessed many times during the past two years. Indeed, who has not seen this particular incident occur time without mention: A great big fellow — the picture of health — who has recently been pronounced physically fit by a regular army officer or some industrial physician, applies for work. By reason of an order in the organization, the doctor must make a complete physical examination before the applicant can be accepted. Under these circumstances two unfavorable things often happen. First, the doctor feels in his own mind that the man is normal and that he most certainly needs no complete examination, and the result is that the work is often carelessly done and time is consumed that costs the company money without bringing any returns. Second, the applicant himself feels that he does not need a complete examination, and consequently the procedure appeals to him as a mockery, with the result that he is annoyed and has a lower regard for medicine in industry.

In order that the many advantages of the physical examination may be conserved, we should now concern ourselves with improving its *modus operandi* by ironing out wrinkles wherever possible. In this connection, why should institutions which require physical examinations not adopt the policy of giving an applicant a card showing his physical condition? Within a limited time, this card plus an examination for acute diseases should be accepted in

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lieu of another *complete* physical examination. These cards could easily be standardized and interchanged between any shops carrying on good medical work.

I can see several excellent results from such a system. First, it would rule out many of the normal cases that require no complete physical examination, and would thereby render two distinct benefits — the doctor's work would become less monotonous, and much time would be saved. I believe that many of the industrial physical examinations have degenerated into a monotonous routine. Indeed, I know of nothing more uninteresting to an intelligent doctor than an examination of numerous normal cases. The time saved could be spent to most excellent advantage in discussing personal or organization affairs, shop conditions or other subjects which aid in determining the employees' ideas of life and industry, and help so much in establishing pleasant personal relations between the dispensary and the plant. Second, I think that the importance and use of the physical examination would appeal much more strongly to the applicant if some written statement accompanied it. It would help make the intangible benefits of the examination more tangible. Do you not think that almost any man would regard with considerable pride a card stating that he was in sound physical condition, or can you not easily imagine that the written card might help impress upon the applicant the seriousness of some existing defects? Might it not lend a personal touch that would help us immensely in selling medical ideas to employees?

PHYSIOLOGICAL EFFECTS OF AUTOMOBILE EXHAUST GAS AND STANDARDS OF VENTILATION FOR BRIEF EXPOSURES

Continued

YANDELL HENDERSON, HOWARD W. HAGGARD, MERWYN C. TEAGUE, ALEXANDER L. PRINCE, AND RUTH M. WUNDERLICH

IV. Concordance of the Standard here Proposed with the Observations of Other Investigators

THE standard defined in Figure 4* may seem, from the work of others, especially that of Haldane, unduly high, if one fixes attention upon the concentration of carbon monoxide in the air breathed; or it may appear unnecessarily low, if stated in terms of the maximum percentage saturation — *i. e.*, complete equilibrium of the blood and the corresponding tension. The work of Haldane is so pre-eminent in this field, alike in amount, thoroughness, and practicality, that discordance between the conclusions drawn from his investigations and the standard here proposed would require elaborate explanation and defence. In fact, however, we believe that when all aspects of the question are taken into consideration our observations and conclusions, although differing in detail, are essentially concordant with those of Haldane (4) (5). Briefly stated, his principal conclusions were as follows:

The symptoms caused by carbon monoxide depend upon the extent to which the hemoglobin has been saturated. The symptoms are due solely to the deficiency of the oxygen percentage in the blood.

When air containing carbon monoxide is breathed, about half of the carbon monoxide actually inhaled is absorbed, except toward the end of the process when absorption is coming to a standstill.

The rate of absorption and time required for symptoms to appear is proportional to the respiratory exchange and may be very much shortened by the increased breathing of exercise.

The symptoms do not become appreciable during rest until the blood is about a third saturated. An individual in this condition suffers from palpitation and throbbing in the head and is liable to become faint or dizzy on any exertion, such as that of ascending a stair, or on sudden exposure to cold air.

In experiments on himself Haldane (6) found that, when 50 per cent. saturated, he could scarcely stand and could not walk alone without falling down. There was giddiness, dullness of the senses, distinct shortness of breath, and labored breathing. In the course of two or three hours after leaving the contaminated air he found that nearly all the carbon monoxide disappeared from the blood, which had then returned to its normal condition. A headache lasting for some hours was likely to ensue from the exposure if the latter were sufficiently long.

In reporting on the conditions which should be maintained in the Underground Metropolitan Railways of London (7), he said:

> Roughly speaking, the probable action on a healthy person of varying percentages of carbon monoxide in the air may be stated as follows: 2.5 volumes per 10,000 would suffice after a sufficient time (after an hour and a half during rest, but very much less during even slight exertion) to cause symptoms just distinctly appreciable on exertion. Five volumes per 10,000 would cause marked dizziness or fainting on exertion, 9 volumes would cause in-

* For figures, see the first part of this article in the preceding issue of the JOURNAL OF INDUSTRIAL HYGIENE.

ability to walk, and about 15 volumes might produce death. . . . Considering the enormous number of people in various states of health who use the railway, . . . it seems desirable that not more than one volume per 10,000 of this gas should be present in the air.

To these statements may be added the fact that Burrell (8) found that after breathing air containing twenty-five parts of carbon monoxide per 10,000 of air for twenty minutes he had at first only a slight headache, but later became ill. The illness lasted for several hours and was accompanied by nausea and headache.

The agreement of these statements with our conclusions is sufficiently close to need no further discussion, until the question of the allowable concentration of carbon monoxide — a concentration producing no appreciable effects in any one — is reached. On this point Haldane recommended one part in 10,000, while we approve concentrations up to four parts, or, with longitudinal ventilation, even six. It is to be noted, however, that the conditions to which Haldane's recommendations applied were in some respects different from those which will occur in a vehicular tunnel. The motive power in the London Underground Railways was at that time (1897) furnished by steam engines burning coke. The engine drivers and train crews and even some passengers might be exposed for considerable periods of time — much longer than we have figured on. Haldane seems to have had in mind the possibility that exposure might be so long that the blood would come nearly into equilibrium with the tension of carbon monoxide in the air breathed and reach a corresponding percentage of saturation. We, on the contrary, are basing our estimates on times of exposure too short for the attainment of more than half the equilibrium degree of saturation.

The apparent discrepancy between the two standards lies in the figures for the concentration of carbon monoxide in the air breathed. If, however, we turn to the more fundamental physiological condition — namely, that of the percentage saturation of the blood — the discrepancy largely disappears. Thus, a glance at Figure 4 shows that thirty-five minutes in an atmosphere containing four parts of carbon monoxide in 10,000 could induce 12 per cent. blood saturation. Now blood which is 12 per cent. saturated is in equilibrium with one part of carbon monoxide in 10,000 of air. In other words, a stay of several hours in an atmosphere of one part of carbon monoxide in 10,000 would involve the same percentage saturation as a stay of thirty-five minutes in four parts per 10,000. Indeed, as the development of symptoms from carbon monoxide is wholly a question of oxygen deprivation, it is safe to assert that a saturation of the blood up to 16 per cent. lasting for only a short period would involve less physiological effect than a prolonged period of saturation at 12 per cent.

On these grounds we have indicated in Figure 4 two standards: (1) for the blood at 12 per cent. saturation, or one to 10,000 tension, for exposures of some hours; and (2) at 16 per cent. saturation, or 1.5 to 10,000 tension, for brief exposures. The whole matter may be even more simply summed up in a single expression involving the time measured in hours, the concentration of carbon monoxide in the air in parts in 10,000, and a constant for each degree of physiological effect. The physiological effects of all concentrations and times (within reasonable limits) may be then defined as follows:

1. Time × concentration = 3, no perceptible effect.
2. Time × " = 6, a just perceptible effect.
3. Time × " = 9, headache and nausea.
4. Time × " = 15, dangerous.

Physical exertion and increased breathing would reduce the constant in the first

equation from 3 to 2, 1, or even less, and would affect the other equations correspondingly. Any standard for any special conditions of time or concentration, within reasonable limits, based on these formulae, is sufficiently concordant both with the recommendations of Haldane and with the summary of our observations and conclusions contained in Figure 4.

Finally, we may here quote from a letter recently received from Dr. Haldane, which was in answer to a letter from us stating the general trend of our observations and findings and in which Dr. Haldane says:

> In the report on the Underground Railway the chemical standard which I recommended if steam traction was continued was .15 per cent. of carbon dioxide, and I pointed out that this would contain about .01 per cent. carbon monoxide. But the standard was not based primarily on the carbon monoxide, but on the general unpleasantness of the air. There was no definite evidence of people being upset by the carbon monoxide, though there was often .03 to .05 per cent. at certain parts of the tunnels and stations; and I even found .066 per cent. of carbon monoxide (with .89 per cent. of carbon dioxide) on the platform of Gower Street Station (near University College). Passengers were never exposed long enough for ill effect, and the men at the stations were probably more or less acclimatised.
>
> At that time I did not know nearly so much about small percentages of carbon monoxide as I do now. Lorrain Smith and I made a lot of experiments on ourselves(to determine oxygen tension of arterial blood) (Jour. Physiol., XX, 1896, and XXII, 1897) and came to the conclusion that anything less than .06 per cent. produced no symptoms after several hours' exposure except some shortness of breath on exertion. Our blood saturations only went to about 28 per cent. (in about one and one-half hours), and no further absorption occurred up to five hours. About a year later we tried a similar experiment and found .06 per cent. far too much for us. I tried again at Oxford later, and now found that even with about .03 per cent. the saturation gradually crept up during four or five hours to over 30 per cent. It became clear afterwards that in the first experiments we had both got acclimatised and were thus abnormally resistant to carbon monoxide.
>
> What I should now say is that with long exposures of several hours anything more than .02 per cent. should be avoided. For exposures of less than an hour .05 per cent. would not be really objectionable. As regards gases from motors, however, the smoke and smell might possibly be worse than the carbon monoxide. On this point I have no experience, though I have run across cases of poisoning where there does not seem to have been much smoke or smell.
>
> You will see from the above that my ideas about carbon monoxide coincide very closely with what your experiments point to. Lorrain Smith and I had not the least idea that by our daily experiments we had become acclimatised and ready to secrete oxygen as soon as our blood saturation rose to about 25 per cent. The absorption was simply stopped short as soon as oxygen secretion began; but an ordinary person does not secrete at this level, so the absorption goes creeping up for hours.

V. Observations in Large Gassing Chamber

The experiments detailed in Section II involve exact, but rather artificial conditions. Exhaust gas is not pure carbon monoxide and the number of persons who could be tested in the 6 cubic meter chamber was quite limited. It appeared essential, therefore, to obtain confirmatory observations under as nearly real conditions and on as many persons as possible. For this purpose a brick building, 30 feet square, with walls 12 feet high at the side, and a hip roof, was erected. Its cubic capacity was approximately 12,000 cubic feet of air, which is about the volume of a section of the vehicular tunnel which will contain one car when the traffic is active.

A Ford car was installed near the middle of this chamber, with a continuous stream of water running into and out of its radiator to prevent over-heating. The axles were supported on a wooden framework so that the rear wheels turned clear of the ground. Against them were pressed two large wooden pulley wheels on a piece of heavy shafting, at the ends of which were wooden paddle wheels. The engine of the car, therefore, ran with a fair load, and the power was expended in mixing the air in the chamber. The paddle wheels did this so

effectively that in a number of tests practically uniform concentrations of exhaust gas were found simultaneously in all parts of the chamber.

The exhaust of the car was connected to a 2-inch iron pipe with a T and two valves. From one valve a pipe led to a large iron can (to equalize pressure) and to a gas meter, and discharged close to one of the paddle wheels, which drew in and distributed the gas. The pipe from the other valve led outside of the building. Thus, by adjusting the valves, all or any part of the exhaust gas could be discharged into the chamber, and its volume read on the meter. Samples of the exhaust gas unmixed with air were taken and analyzed for carbon monoxide in an Orsat apparatus, using ammoniacal cuprous chloride as the absorbent. The percentage ranged between 5.5 and 6.8 per cent., with an average of about 6 per cent. The engine discharged a total of about 25 cubic feet of exhaust gas per minute, from which we calculated that approximately 1.5 cubic feet of carbon monoxide were produced by the car per minute.

Diffusion from the chamber through the walls and roof, and through cracks around the doors and windows, was considerable. Whenever the engine was stopped, there was thus a drop of about one-third of the concentration of carbon monoxide in fifteen minutes. Usually the entire exhaust of the engine was discharged through the meter into the chamber until the desired concentration of carbon monoxide was approximately reached. Thereafter, a part of the gas was discharged out of doors, and only enough was passed into the chamber through the meter to compensate for loss by diffusion. Samples of the air in the chamber were taken at intervals during the period of exposure, and the amount of carbon monoxide determined either by means of iodine pentoxide (with a correction for vaporized gasoline), or by the blood carmine method, or in both ways. Some discrepancies will be found in the analytical data, but it must be kept in mind that the methods are difficult and the amounts of the substance are minute far beyond the range of ordinary gas analysis.

With practice, considerable facility in controlling the concentration of carbon monoxide in the chamber was attained. The experimental conditions were quite realistic. The car was old and had had rough treatment, and the engine was somewhat irregular in action. The exhaust gas was, therefore, contaminated with at least as much gasoline, oil and soot, and other substances, in addition to water vapor, carbon monoxide and carbon dioxide, as may be met with in any well-regulated vehicular tunnel. Owing to the fact that vaporized gasoline and other constituents of exhaust gas beside carbon monoxide act upon iodine pentoxide, the figure 0.6 was determined as the factor by which it was necessary to multiply the iodine liberated in analysis of chamber air for the estimation of the carbon monoxide.

In this chamber groups of a dozen or more persons at a time sat or moved about for periods of one hour. In addition to the staff of this investigation a number of students of the Yale Medical School served as subjects. We take this opportunity to recognize the intelligent interest manifested, and the valuable service rendered by these young men and women.

After the tests the general condition and feelings of the subjects, particularly the occurrence or absence of headache, were noted. When the subjects had breathed fresh air for five minutes after leaving the chamber, samples of lung air, obtained by having them rebreathe repeatedly into a small rubber bag, were analyzed for carbon monoxide. In such analyses the gas found is that which has diffused out of the blood into the lung air, and the analytical data indicate, therefore, the tension of the car-

bon monoxide in the blood. The effect of running up and down four flights of stairs was also noted, as exercise markedly intensifies asphyxial symptoms.

Only a few typical protocols of these tests can be given in this abbreviation of our report, but the whole of the data may be summarized by the statement that, so long as the standard worked out in the previous section was not exceeded, no appreciable ill effects were induced in any of the numerous subjects. Above this standard, however, headache resulted in nearly all cases, and in some persons nausea and vomiting also occurred.

Details of Observations in Tunnel Gassing Chamber

Protocol 1. — Feb. 4, 1920. The engine of the car was started and maintained at a uniform speed for twenty minutes. Determinations were made of the carbon monoxide percentage in the exhaust from the engine (analyzed with Orsat apparatus), and of the concentration of the gas in various parts of the chamber (by the iodine pentoxide method). For the latter purpose, two positions were chosen: No. 1, 6 feet to the west of the exhaust; and No. 2, 9 feet to the north of the exhaust.

TABLE 3. — EXPERIMENTAL CONDITIONS AND PHYSIOLOGICAL DATA (*Protocol 1*)

Time	Concentrations of CO in Positions		Remarks
	1	2	
Minutes	*Parts in 10,000*	*Parts in 10,000*	
0	0.5	0.3	engine started.
5	3.0	3.0	exhaust gas = 5.6 per cent. CO (by Orsat).
10	5.5	5.0	
15	6.5	7.0	smoke very unpleasant.
20	8.0	8.0	engine stopped; smoke in chamber extremely irritating to eyes.
30	6.0	6.0	pulmonary air of H. W. H., a few minutes after leaving chamber, contained 3.1 parts CO; severe headache and some nausea for four hours; insomnia later.
90	1.5	...	gas slowly diffusing out of chamber.

At the end of twenty minutes the smoke in the chamber had become quite disagreeable and the engine was stopped. The dispersing fans were, however, continued in operation by means of an electric motor, and air samples were taken at intervals. The pulmonary air of H. W. Haggard, who had been in the chamber up to this time and who had been actively at work on the car, was taken a few moments after he left the chamber and analyzed. The data obtained are given in Table 3.

Protocol 2. — Feb. 11, 1920. The procedure was similar to that described in Protocol 1. Continuous and snap samples of air were taken during the period of gassing in three places: position 1, northwest corner; position 2, northeast corner; and position 3, middle of south side of chamber.

TABLE 4. — EXPERIMENTAL CONDITIONS (*Protocol 2*)

Time	Concentration of CO in Positions		
	1	2	3
Minutes	*Parts in 10,000*	*Parts in 10,000*	*Parts in 10,000*
12	3.0	4.0	3.5
24	4.0	4.0	4.0
34	4.0	4.0	4.0
46	4.0	4.0	4.0

The number of persons in the chamber was eighteen — fifteen men and three women. Four subjects were seated about position 1, four about position 2, five about position 3, and the last five were ambulatory. The normal pulse and respiration were observed on each subject some time before gassing, and the same data obtained again soon after gassing. The air analyses were made by the iodine pentoxide method. The engine was allowed to exhaust into the chamber for six minutes initially, and the gas was then shunted to the outside for eight minutes. Thereafter, the exhaust gas was discharged into the chamber for one and one-half minutes in each ten minutes. Table 4 gives the conditions in the chamber as shown by analyses, and Table 5 presents the physiological data obtained from eight subjects — two typical of each group.

Protocol 3. — March 13, 1920. The arrangement of the engine exhaust previously described was altered by the introduction of a baffle can and a large gas meter into that portion of the piping which admitted the gas to the chamber. The volume of gas admitted into the chamber was thus more accurately controlled. A survey experiment, identical with the gassing procedure carried out in Protocol 2, was per-

TABLE 5. — PHYSIOLOGICAL DATA (*Protocol 2*)

Subject	Sex	Position in Chamber	Duration of Exposure	CO in Pulmonary Air after Gassing	Pulse		Symptoms
					Normal	After Gassing	
			Hours	*Parts in 10,000*			
C. Pepe	male	1	1	1.12	90	74	none
E. Shorr	"	1	1	0.99	75	80	"
E. Waters	"	2	1	1.35	108	82	"
M. Hotchkiss	female	2	1	1.16	..	..	"
M. Bell	"	3	1	1.21	..	..	"
E. Hilton	male	3	1	1.06	..	..	"
E. Levy	"	ambulatory	1	0.99	..	..	"
M. Snow	"	"	1	1.27	..	..	"

formed. Determinations were made upon the air in the chamber and the pulmonary air of the subjects by the Haldane blood method. Observations were made on seventeen men and one woman. The subjects were for the most part quite active during this experiment.

The concentrations found by these methods, those estimated from meter readings, and analyses of exhaust gas by the Orsat apparatus, allowing for loss by diffusion, are shown in Table 6; the physiological data, which were obtained, in Table 7.

TABLE 6. — EXPERIMENTAL CONDITIONS[1]
(*Protocol 3*)

Time	Exhaust Gas through Meter	Exhaust Gas by Orsat Analysis	Concentration of CO in Chamber
Minutes	*Cubic Feet*	*Per Cent.*	*Parts in 10,000*
0	300	6.4	...
10	80	...	...
15	...	...	6.8
20	75	...	...
30	82	...	9.0
35	...	6.6	...
40	78	...	8.6
50	78	...	...
60	...	...	9.3

[1] From the figures in column 4, the mean concentration of carbon monoxide breathed for one hour may be estimated to have been at least nine parts per 10,000 of air, and from the Orsat figures, column 3, perhaps two or three parts higher.

Exposure of Horses to Exhaust Gas. — A few observations were made on two U. S. Army artillery horses. They were of the Percheron breed and weighed between 1,400 and 1,800 pounds, one bay and the other white. We are greatly indebted to Colonel R. E. D. Hoyle, Commanding Officer, Field Artillery Unit, R. O. T. C., stationed at Yale University, for the loan of the animals.

The car and motor were taken outside of the tunnel gassing chamber and the exhaust gas piped to the inside. The horses were not hitched, but were allowed to move about freely inside the chamber. In each experiment a blood sample was drawn from the ear before and after gassing. The results of the three experiments are shown in Table 8.

Owing to the fact that the dispersing fans were not in operation we believe that the concentration of gas was quite variable in different parts of the chamber; and it is probable that the atmosphere which the horses actually breathed contained considerably higher concentrations of carbon monoxide than the figures given in the table.

VI. Observations in Garages and in the Grand Central Station, New York City

The occurrence of fatalities in small private garages during cold weather has become so frequent an item of news that the public is becoming aware of the danger. Evidently if a car, while warming up, gives off 1 cubic foot of carbon monoxide per minute in a room 10 × 10 × 20 feet, the atmosphere will, apart from diffusion,

TABLE 7. — PHYSIOLOGICAL DATA (*Protocol 3*)

Subject	Sex	CO in Pulmonary Air after Gassing	Pulse at Rest		Symptoms
			Normal	After Gassing	
		Parts in 10,000	*Per Minute*	*Per Minute*	
G. Gildersleve.....	male	2.7	82	96	dizziness, extreme headache and some nausea.
A. Vanderberg.....	"	2.9	72	90	throbbing headache for several hours, general lethargy for 24 hours.
A. Dreher.....	"	2.2	82	105	headache, nausea, chill.
J. Olean.....	"	1.9	82	102	dizziness immediately after gassing, sharp headache for 9 hours.
L. Peroff.....	"	1.8	74	100	throbbing headache for 9 hours.
M. O'Connell.....	"	3.0	72	130	frontal headache for 6 hours.
J. Fleming.....	"	2.7	86	130	severe headache, vomited, in bed 5 hours.
E. Waters.....	"	2.7	82	120	severe headache for 20 hours, legs weak.
M. Glazer.....	"	2.7	60	84	severe headache lasting 5 hours.
H. Farrell.....	"	2.5	76	90	severe occipital headache for 8 hours.
E. Tolstoi.....	"	1.9	72	120	severe headache, dizzy, nauseated, ringing in ears, for 7 hours.
E. Shorr.....	"	2.5	74	116	persistent headache and nausea for 8 hours.
H. Bailey.....	"	1.6	75	80	severe headache and nausea for 6 hours.
H. Langner.....	female	2.2	72	108	pounding in ears, violent headache and nausea, headache for 48 hours.
E. Wakeman.....	male	1.8	50	60	severe headache, faintness for several hours.
A. Wakeman.....	"	2.0	54	68	headache and nausea.
P. Susman.....	"	2.2	80	120	severe headache and vomiting.
J. Sigal.....	"	1.8	72	..	very faint and weak, severe headache for 72 hours.

reach the dangerous concentration of fifteen parts in 10,000 in three minutes. Owing to the insidious and usually accidental character of carbon monoxide poisoning in such garages, however, nothing bearing particularly on our problem is to be learned from them which could not be more accurately determined in our experimental chamber.

TABLE 8. — RESULTS OF EXPOSURE OF HORSES TO EXHAUST GAS

Date	Time	Concentration of CO in Chamber	Percentage Saturation of Blood		Remarks
			White Horse	Bay Horse	
	Hours	*Parts in 10,000*			
3 17 20	1	2.5	..	11	no symptoms
3 17 20	1	5.0	20	20	"
3 19 20	1	5.0	23	25	"

At first it would appear that important information might be obtained from the conditions occurring in large public garages and repair shops. On investigation of a number of such places we found that, even in those recently built and supplied (usually more or less imperfectly) with artificial ventilation, the employees frequently have slight headaches, while severe headache, nausea and emotional disturbances, ranging from mere unreasonableness up to hysterical mirth, anger or grief, or even maniacal manifestations, are not very unusual. There seems to be a general recognition that "it is not gasoline but the burnt gas" which produces these conditions. Our inquiries have also elicited information regarding an occasional death in which the victim had crawled under a car when its engine was running, or when the engine of a standing car ahead was "idling." When it came to getting samples of air for analysis from garages, however, we soon found that we could get anything that we wanted,

high or low, and that the figures had, therefore, little value without more elaborate supervision of the personnel than we could provide.

Conditions such as may occur in tunnels appear to be afforded in the taxicab driveway and stand below the Grand Central Railway Station, New York City. The general public passes through this place, many thousands per day. The taxicab drivers sometimes wait half an hour for a passenger, and the starters and markers are on duty for four or five hours at a time.

We learned on inquiry that up to a few months before this investigation a type of car had been in use which produced a considerable amount of smoke and that at that time headache and nausea were common. Recently, however, another type of car producing very little smoke has been introduced and symptoms of gassing appear now to be rare.

In order to define the conditions at the taxicab driveway and stand, members of the staff of this investigation spent several hours near the starters' position and took a number of samples of air for analysis, with the following results:

March 12, 1920. A mild, damp afternoon and evening. *5.45 P.M.* A sample of air taken soon after a number of cars had gone through contained 0.36 parts carbon monoxide in 10,000.

9.45 P.M. A sample taken after forty cars had gone through in fifteen minutes contained 1.36 parts carbon monoxide in 10,000.

10.35 P.M. After three cars had passed in ten minutes, the carbon monoxide concentration was 0.45 parts in 10,000.

11.30 P.M. Fifteen cars passed through in five minutes. A sample taken ten minutes later contained 1.78 parts in 10,000.

On another occasion a series of samples were taken and yielded the following figures: 0.45, 1.78, 0.36, 2.12, and 1.47.

It appears from these data that the air is occasionally vitiated for a time with as much as two parts of carbon monoxide in 10,000, but that with the ventilation provided by large fans the concentration of carbon monoxide soon falls again decidedly below one part in 10,000. There are now, so far as we can learn, no complaints from the public, and the taxicab drivers have only an occasional headache, when a line of cars stands for a long time with engines running.

VII. Comparative Toxicity of Pure Carbon Monoxide, Illuminating Gas, Exhaust Gas from Gasoline, Exhaust Gas from Coal Distillate and Gasoline Vapor

The general agreement between the experiments with pure carbon monoxide mixed with air in Section II and the results with exhaust gas in Section IV indicates strongly that in the concentrations occurring in the large chamber carbon monoxide was the only substance of sufficient toxicity and present in sufficient amount to have any considerable physiological effect. All of the data in both of these series of experiments were, however, based upon low concentrations of the gas and the deductions from them might not apply equally to high and lethal concentrations.

We have, therefore, thought it well to check these results by means of observations on animals in high concentrations of gas. For this purpose dogs were used. The animal in each case was placed in a cube-shaped plateglass chamber measuring about 3 feet on a side. The gas to be tested was mixed with air in a gasometer of several hundred liters capacity, so that the carbon monoxide concentration was about 0.3 to 0.4 per cent., or thirty to forty parts in 10,000. From the gasometer the gas mixture was passed into the chamber through a tube by a small electrically driven air blower. Another tube from the chamber led outdoors. Usually the gas was run in at such a rate that the animal was at the point of death in thirty to thirty-five minutes.

The animal was then removed from the chamber and a sample of blood was drawn for analysis by the carmine titration method.

The technical details of the analysis of carbon monoxide in air and in blood will be found in the full report.

(*a*) *Experiments with Pure Carbon Monoxide Mixed with Air.* — In this atmosphere the animals became unconscious with no more apparent discomfort than if anesthetized with ether. The blood of five dogs at the point of death contained the following percentages of carbon monoxide: 87, 82, 84, 79, 88; average 84.

(*b*) *Experiments with Illuminating Gas Mixed with Air.* — In such an atmosphere the symptoms during intoxication differed in some respects from the preceding group. There occurred in all cases more rapid collapse and distinctly greater respiratory excitement. Nausea and vomiting, which were lacking in the experiments with pure carbon monoxide, occurred in all the animals of this second group. These observations and the fact that death ensued though a lower percentage of carbon monoxide existed in the blood indicate that illuminating gas contains some substance, or substances, which render it distinctly more toxic than an equal amount of pure carbon monoxide. The blood of the five dogs used in these experiments contained at the point of death the following percentages of carbon monoxide: 74, 67, 76, 71; average 70.

(*c*) *Experiments with Exhaust Gas from a Car Using Gasoline.* — For these tests the three commonest varieties of gasoline sold locally were used successively. A large rubber bag was attached to the exhaust of a car (one in good condition, with an efficient and smooth running engine), while it was standing with the engine running "idle." This gas was analyzed for carbon monoxide by means of an Orsat apparatus in the usual way. The gas was then mixed with air in the large gasometer to approximately the same concentration of carbon monoxide as in the previous experiments and was then administered to animals in the glass chamber. In these experiments the animals were at the point of death in approximately the same time as in the first series of experiments under (*a*) above. The symptoms were similar to those from pure carbon monoxide and unlike those from illuminating gas. The percentages of carbon monoxide in the blood were also similar to the first series, but higher than the second. Evidently carbon monoxide was here practically the only toxic substance. The blood of the five dogs used in this group of experiments contained at the point of death the following percentages of carbon monoxide: 84, 86, 83, 81, 81; average 83.

(*d*) *Experiments with Exhaust Gas from a Car Using Coal Distillate.* — For the opportunity to make these tests, we are indebted to the New Haven Gas Company which very kindly sent a car charged with coal distillate to the laboratory and allowed us to obtain a bag of exhaust gas as in the preceding experiments. Two dogs were exposed to this gas, exactly as the animals had been exposed in the previous experiments to exhaust from gasoline, and died with symptoms like, but more marked than, those of the dogs poisoned with illuminating gas. The blood of these two animals had a decided brownish tinge indicating a marked destructive influence upon the hemoglobin of the blood. It is known that benzol has such an effect.

The composition of the coal distillate, according to figures kindly furnished by the chemist of the Gas Company, was:

Benzol	69.0	per	cent.
Toluol	15.5	"	"
Solvent naphtha	13.5	"	"
Heavy naphtha	2.0	"	"
Total	100.0	"	"

The blood of the two dogs used in these experiments contained at the point of death the following percentages of carbon monoxide: 60, 64; average 62.

(*e*) *Experiments with Gasoline Vapor.* — The results of our experiments with gasoline vapor are given in *The Anesthetic and Convulsant Effects of Gasoline Vapor*, by Howard W. Haggard (9).

VIII. Principal Conclusions

The general standards at which we arrive (pp. 86–89* and 138) are: When the time in hours multiplied by the concentration of carbon monoxide in parts per 10,000 of air equals 3, there is no perceptible physiological effect. When it equals 6, there is a just perceptible effect. When it equals 9, headache and nausea are induced. When it equals 15 or more, the conditions are dangerous to life.

If the volume of breathing is increased by exercise (even by slow walking, and correspondingly more by physical work) the rate of absorption of carbon monoxide is increased proportionally.

* See the preceding issue of this Journal.

After return to fresh air, the elimination of carbon monoxide through the lungs proceeds at a rate of 30 to 60 per cent. reduction of the blood saturation per hour.

In the exhaust gas from gasoline, carbon monoxide is the only considerable toxic constituent. In the exhaust gas from coal distillate (benzol, etc.), and in illuminating gas, there are present accessory toxic substances.

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BOOK REVIEWS

The Community Health Problem. By Athel Campbell Burnham, M.D., Health Service, Atlantic Division, American Red Cross; Attending Surgeon, Volunteer Hospital, New York City; Lieutenant Colonel, Medical Reserve Corps, U. S. Army; Fellow New York Academy of Medicine. Cloth. Pp. 149 and index. New York: The Macmillan Company, 1920.

This book is a brief and readable presentation of public health material, well suited for non-technical courses in general hygiene. The author has desired to give his readers a conception of the various fields into which preventive medicine has crept and the manner and success with which it has operated. Industrial hygiene is included in this group and receives brief but discerning treatment.

It is unfortunate that a chapter is not devoted to the various types of workers necessary in the different branches of community health, together with a certain amount of information as to their training. The practical usefulness of the book for elementary students would be augmented by such an addition. — *Cecil K. Drinker.*

Human Efficiency and Levels of Intelligence. By Henry Herbert Goddard, Director of the Bureau of Juvenile Research of Ohio. Cloth. Pp. 128. Princeton: Princeton University Press, 1920; London: Oxford University Press, 1920.

It is no exaggeration to say that this short series of lectures, delivered at Princeton University in April, 1919, enunciates a point of view that should not only be understood by everyone interested in efficiency and hygiene problems, but also by every citizen who wishes to cast an intelligent vote. Although no original work is published in the book, it brings together evidence from various sources in such a convincing, even dramatic way, that the reader finds himself awakened to the realization that the *doctrine of mental levels* is a social conception of the first magnitude.

The doctrine stands mainly on two well-established facts: first, that the intellectual development is largely independent of what we call learning or knowledge; second, that not all persons develop to the highest level or even near to it; many stop at some one of the lower levels of childhood.

The important thing for us to learn from the book is that the number of people of relatively low intelligence is vastly greater than is generally appreciated, and that this mass of low level intelligence is a menace to democracy unless it is recognized and properly treated. The data are obtained from several sources — the experience at institutions for the feeble-minded, the Bureau of Juvenile Research in Ohio, the statistics of the Department of Labor, school statistics from the Department of Education, and the report of the General Staff on Psychological Tests in the Army. The sources are authoritative, and the fact that remarkably similar figures are obtained from each source forces us to accept the statements as proven facts, however upsetting these facts may be to our preconceived ideas that we are all born equal. The army figures show that 70 per cent. of the 1,700,000 men examined were below the mental age of fifteen, and that 25 per cent. were morons. These figures being from the drafted army must certainly be a fair sample of our whole male population. The school figures from the Department of Education show that 67 per cent. of schoolchildren do not finish the eighth grade, and that 26 per cent. do not finish the fifth grade — a result remarkably parallel to the army figures. The Department of Labor tells us that 68 per cent. of wage earners get less than $15 a week — at least, an analogous observation.

Can we hope to have a successful democracy when the average mentality is thirteen? The answer is that the social efficiency of a group of human beings depends upon recognizing the mental limitations of each one and of so organizing society that each person has work to do that is within his mental capacity and at the same time calls for all the ability that he possesses. In short, whenever the 4 per cent. at the top of the scale choose to devote their superior intelligence to understanding the lower mental levels and to the problems of the comfort and happiness of the other 96 per cent., they will be elected the rulers of the realm and then will come perfect government. But that 4 per cent. must have what we call the "human quality" and must learn to take seriously the responsibility of their position — they must have the desire to make all people happy. Then, in a democracy where every person has the right to vote for those who shall rule over him, the masses will vote for the best and most

intelligent if they are made to feel that these same intelligent people have the welfare of the masses at heart.

The failure to appreciate the facts upon which the doctrine of mental levels is based has resulted in a vast amount of delinquency, and such delinquency impairs the efficiency of the total group to an extent little appreciated. It is no longer to be denied that the greatest single cause of delinquency and crime is low grade mentality. Apart from delinquency these people, in their present disorganized state, are extremely inefficient. It is their history (so constant as to be almost diagnostic) that they are constantly changing jobs. We have made no serious attempt to fit the man to the job. No attempt has ever been made to ascertain what grade of intelligence is required of any of the multitude of occupations. Some progressive employers in industries have inaugurated a sort of tryout system; but this is a crude makeshift in comparison to the results of a scientific determination of the mental level of the individual, coupled with a study of the amount of intelligence required for particular work.

"When one contemplates the enormous proportion of misfits that must exist in the industrial world and that such misfits mean discontent and unhappiness for the employee, one can but wonder how much of the present unrest in such circles is due to this fact. A man who is doing work that is well within the capacity of his intelligence and yet that calls forth all his ability is apt to be happy and contented and it is very difficult to disturb any such person by any kind of agitation." — *Stanley Cobb.*